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In this artist's depiction, astronauts get a lift from Boeing's Starliner, one of two spacecraft offering NASA limo service.

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COVER: Photographer Britt Dietz caught the Planes of Fame Air Museum's F-86 Sabre in mid-maneuver as pilot Steve Hinton performed at the museum's 2017 Chino, California airshow. Not all early jets were as well behaved as the F-86 (see p. 44).

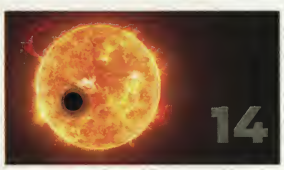
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Viewport

FROM THE DIRECTOR OF THE NATIONAL AIR AND SPACE MUSEUM

Great Times for Science

WHEN I TALK TO SCHOOL KIDS around the country, I tell them how lucky they are to be studying science now, at this moment in the history of space exploration. When I started out in science, we had only nine planets to study, and that number soon shrank to eight when we demoted poor Pluto. By the time my young audiences are in graduate school, they will have literally hundreds of planets to investigate.

One reason for this coming wealth of other worlds is the NASA mission TESS, the Transiting Exoplanet Survey Satellite. During its two-year primary mission, TESS is expected to find 1,500 planets orbiting nearby stars, and among those, to identify 50 rocky, Earth-like or potentially habitable planets (see p. 34). Imagine: Three decades ago, we didn't know of a single planet beyond our solar system; today, based on the work of NASA's previous planet-hunting mission, Kepler, we know there are many thousands, and we are about to find 50 near us that could harbor life.

The search for life beyond Earth—in our own solar system with missions to Mars or to the moons of Jupiter and Saturn, as well as in solar systems beyond our own—is an enormous undertaking that cuts across many disciplines. As the National Air and Space Museum embarks on our own enormous undertaking of Transformation—reimagining our galleries and using technology to tell the stories of aviation and space exploration—we hope to explore the big, exciting ideas in exploration today, like what ingredients are required for life and how our experience with life on Earth tells us what to look for on other worlds.

Science also works in the reverse: We study other planets to learn more about our own. Planetary scientists today rarely specialize in a single planet; instead, they study the processes that shape and affect them all. I'm a planetary volcanologist, so I study volcanoes across the solar system to figure out how they work. The ultimate goal is to answer questions and make predictions about volcanoes on Earth. No one knew, for example, that the Kilauea volcano in Hawaii was going to erupt in the dramatic fashion we watched in May. No one can tell when the eruption will end or exactly where the next fissure will open. In studying other planets, we hope to get information that bears on these kinds of scientific puzzles on the planet where we live.

That's something I'm going to be thinking about too as I look at Transformation: Do our galleries, our website, and our social media connect current scientific discovery and technological advances to how we live? We want people to come to the Museum not just to understand the past but also to understand the present in the context of the past and to use the Museum as a way to look to the future.

I tell students that this is an exciting time to be doing science. This is also a very exciting time to be leading the National Air and Space Museum.

ELLEN STOFAN IS THE JOHN AND ADRIENNE MARS DIRECTOR OF THE NATIONAL AIR AND SPACE MUSEUM.



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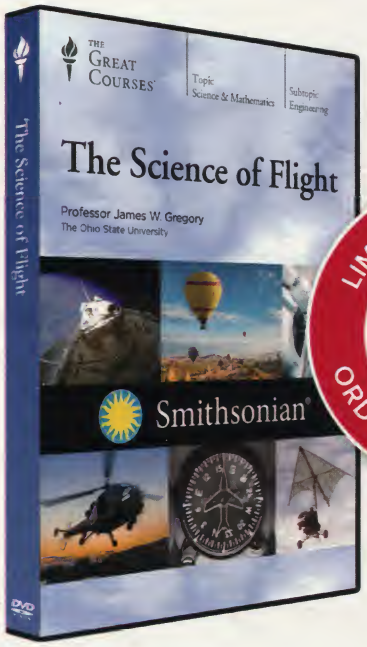
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Letters

WRITE TO US AND FOLLOW US

More Than a Rocket Man

Your article about Tory Bruno ("The Other Rocket Man," June/July 2018) brings attention to a major leader in the U.S. launch industry who's not well known. I wish I'd been able to update my remarks, which were from a 2016 interview. I would have added that Bruno has reduced prices on the Atlas [rocket], proposed a path to reduce reliance on Russian engines (as directed by Congress), and put forward innovative ideas for United Launch Alliance's next rocket, the Vulcan. Bruno is also on the User Advisory Group for the National Space Council, along with other space launch leaders, and I would have mentioned that as well.

SCOTT PACE
Executive Secretary
National Space Council
The White House

Lancaster Love

There's an Avro Lancaster ("RAF 100," June/July 2018) in storage in Toronto, owned by the city, and there is much debate regarding what museum will be given the privilege of custody over it, with the goal of restoring it to flight status. I hope to see another Lancaster take to the skies in the not-so-distant future; as a son of a Lancaster pilot who completed 50 operations over enemy territory, I feel this project could pay tribute to the almost 10,000 Canadians who were lost in the skies over Europe during World War II.

DAVID R. THOMPSON
Abbotsford, British Columbia

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The other flying Lancaster is with the RAF, and is based at Waddington, Lincolnshire in the U.K. I was born and raised in Boston, Lincolnshire, which was surrounded by aerodromes during World War II, some of which were later taken over by the Eighth Air Force and their B-17s. St. Botolph's, the parish church, has an extraordinarily tall tower, called the "Boston Stump," and this was the rallying point for the big raids, and it took a few hours for the Lancasters to form up. We would bike the 10 miles to the aerodrome to see the Lancasters and the B-17s, which was a spectacular sight.

DAVID A. PSETELL
London, Ontario
via email

Antiques Roadshow

Great to hear of Willie remaining in service, and especially in electronic warfare. ("My Week With Willie the Whale," Apr./May 2018.) I flew in Willie, the RF-4, and the EA-6A during two Vietnam tours. Years later I piloted Hueys, another craft that wouldn't die. Come to think of it, I haven't either.

JOSEPH SCHVIMMER
via email

The Road to Hell

Anatoly Zak's article ("Inside a Soviet ICBM Silo," June/July 2018) provides an amazing look at one of the most terrifying weapon systems ever created. Mr. Zak said that the journey to see Satan was treacherous and troubled. If I had only known, I could have saved him time and effort: my mother-in-law lives just three hours away.

SCOTT P. TUDOR
Maumelle, Arkansas

Corrections

June/July 2018 "RAF 100": (1) The Canadian Warplane Heritage Museum is located in Mount Hope, Ontario, not New Hope. (2) The original B-25 known as *Grumpy* flew with the RAF's 98 Squadron, not 99. (3) Although the DHC-1 Chipmunk was used by the British as a trainer, it was designed by de Havilland Canada. In "Combat Is the Mother of Invention," the photo credit on page 48 was misspelled; it should be "Ned Costa." The photograph on the Contents page should have been identified as an Atlas rocket not a Delta.

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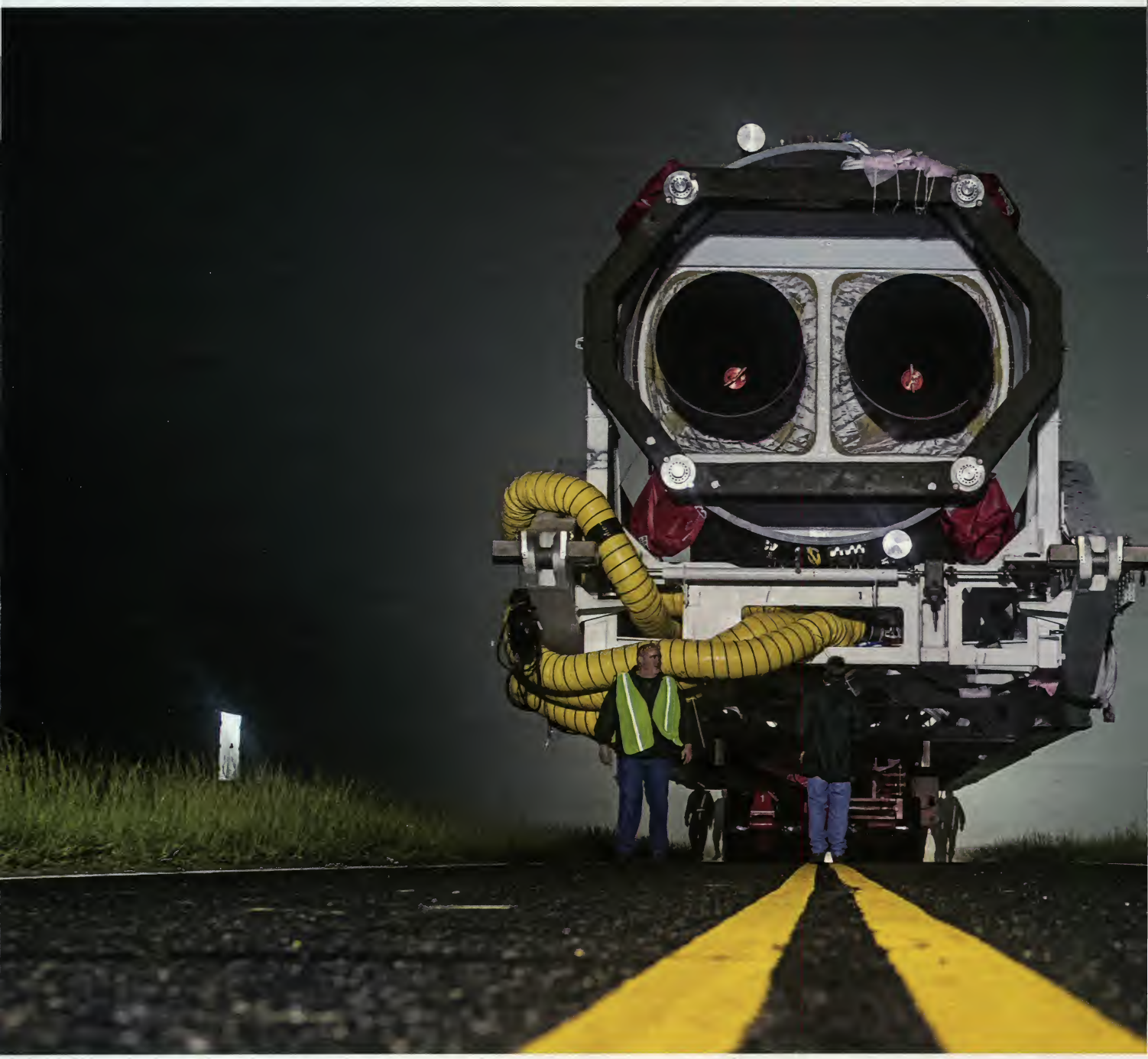
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What's Up

IN THE SKY, IN SPACE, AND IN THE NEWS



ORBITAL ATK EMPLOYEES ensure that nothing will disrupt their Antares rocket stage during its mile-long journey from integration facility to Launchpad-0A at the Mid-Atlantic Regional Spaceport, on NASA's Wallops Island Flight Facility in Virginia. Late last May, four days after its nighttime crawl, the two NPO Energomash RD-181 engines (which in the photo look like the eyes of a cartoon face) successfully launched an uncrewed Cygnus capsule filled with nearly 7,400 pounds of supplies to the International Space Station (ISS).

The capsule included scientific experiments, encompassing both advanced technology (the Cold Atom Lab, which uses lasers to enable researchers to examine

NASA/AUBREY GEMIGNANI



atoms at temperatures near absolute zero) and ancient arts (a hand-held mechanical sextant, a tool with centuries of history, to test back-up navigation methods).

The core stage powered Orbital ATK's eighth delivery (ninth attempt; one 2014 launch failed) in a contract through which NASA buys ISS supply flights from corporate providers. It's the spacefaring equivalent of chartering a single airplane flight instead of buying the whole airplane. By buying such flights, NASA hopes to jump-start the space industry in the same way the U.S. Postal Service nurtured the heavier-than-air flight industry through mail delivery. (Orbital ATK was acquired by Northrop Grumman in June.)

100 Seconds to 10,000 Feet



There was nothing but blue sky—and the few instruments not ripped out for weight—in pilot Dan Gray's view while he pitched up at nearly 60 degrees for his record-breaking climb.

DAN GRAY DIDN'T NEED a whole 15 minutes of fame—100 seconds was plenty. That's how long it took Gray to pilot a highly-modified kitplane—an experimental Vans RV called a Harmon Rocket—from zero to 10,000 feet and straight into the record books.

Gray's company, Aviation F/X, was approached by Australian Harmon Rocket owner Russ MacFarlane, who, with help from his son Eric, was preparing the aircraft for an attempt on the time-to-climb record (for airplanes weighing about 1,100 to 2,200 pounds). Gray and the MacFarlanes started with the basics: Reducing weight by ripping out everything not critical to flight, including the wingtips, wheel pants, and passenger seat. They even replaced the stock tailwheel with a skateboard wheel.

But the real magic was from the firewall forward: The traditional Lycoming engine was replaced by a twin-rotor Mazda rotary mated to a rotor drive from a Bell 47 helicopter. MacFarlane is "a real lover of rotary engines," says Gray, and saw an opportunity to promote them by using one to break a record. Despite the high power-to-weight ratio of a rotary engine, few airplanes fly with them today because they burn a lot of gas—except at wide-open throttle, says Gray, and that is how he planned to use it. The engine used a massive GT40 turbocharger, which crammed air in at more than twice atmospheric pressure, and a diet of pure methanol—typically used by race cars to cool the intake charge—to increase the engine power output from 150 hp to more than 600 hp, albeit for only a few seconds. In flight, with controls trimmed for climbing, the aircraft still put out 500 hp at 8,500 rpm.

In ground tests, the distinct scream of the rotary could be heard more than a mile away, and the engine was powerful enough to tow a truck with its parking brake on. To make sure the engine systems could handle the extreme angle of climb, the team mounted the airplane on a lifting-bed truck, inclined the bed 60 degrees, and ran the engine at full throttle.

Gray, who is also a 787 captain for United Airlines, has accumulated 35,000 hours of flight time in a

AVIATION F/X/ MAURIZIO PERISSINOTTO (2)

THE COUNT

3.087 PETAFLOPS

That's the speed of the world's fastest supercomputer (FLOPS stands for floating point operations per second), three times faster than its predecessor. ATERUI II, which started operating in Japan on June 1, will run massive astronomy simulations, like the birth of the universe.

vast array of aircraft and needed all that experience for this project. On one test flight, after a faulty oil line spit oil over the front of the canopy, he was forced to land looking backward. The final flight to 10,000 feet proved relatively uneventful, though, Gray admits, "It's a challenging-flying airplane and a finicky motor. But it was only made to do one thing: climb." At 100 seconds, the Harmon Rocket was a mere eight seconds behind the time-to-climb record set by a certain famous raceplane in 1972. Watch out, *Rare Bear*.

ERIC STEWART

Watch a video of the flight at *airspacemag.com/climb*



A Double-Headed Mustang Flies Again

If you're at the Oshkosh fly-in this July, you may get to see this XP-82 Twin Mustang fly after a 10-year restoration.

"WE BOUGHT THAT AT Walmart. They had a special on them," jokes Tom Reilly on a video posted in May about the custom-made and beautifully shiny outboard gear doors he just received. Reilly is one of the most experienced restorers alive today, and he's at the tail-end of a massive project to bring a rare aircraft back to the sky. In 2008, he acquired an XP-82 Twin Mustang. The prototype was based on the P-51 Mustang, although the two types actually have few parts in common. F-82s mostly served in the Korean War as long-range escorts and, equipped with early versions of airborne radar, as night fighters.

Reilly's team, based in Douglas, Georgia, was able to make good progress because of some staggering good luck, like stumbling upon a left-hand turning Merlin engine (the XP-82's two propellers are counter-rotating) in Mexico City, and finding a fuselage piece owned by a guy who would only give it up in trade—for a nearly impossible-to-find windshield that Reilly just happened to have. The effort put into this scavenger hunt wasn't to make a museum piece. At the time of writing, Reilly and friends intend to show it off in flight at the Experimental Aircraft Association's annual Oshkosh, Wisconsin fly-in this July.

HEATHER GOSS

DEPARTURES

ALAN BEAN

THE ONLY ARTIST to walk on the moon died in May at 86. Alan Bean brought his extraordinary experiences as Apollo 12's lunar module pilot and as commander of the second Skylab mission back with him, sharing them through a large collection of paintings.

Bean was an aerospace engineer and a highly skilled Navy test pilot before he joined NASA. After eight hours on the moon, 59 days orbiting in Skylab, and 18 years as an astronaut, he resigned to become a full-time artist. In 2009, more than 50 of his paintings were exhibited at the National Air and Space Museum, to celebrate the 40th anniversary of the first moon landing. See a selection at *airspacemag.com/bean*.



NASA *did* send a poet: Alan Bean's legacy is reminding us that the best part of exploration is sharing it.

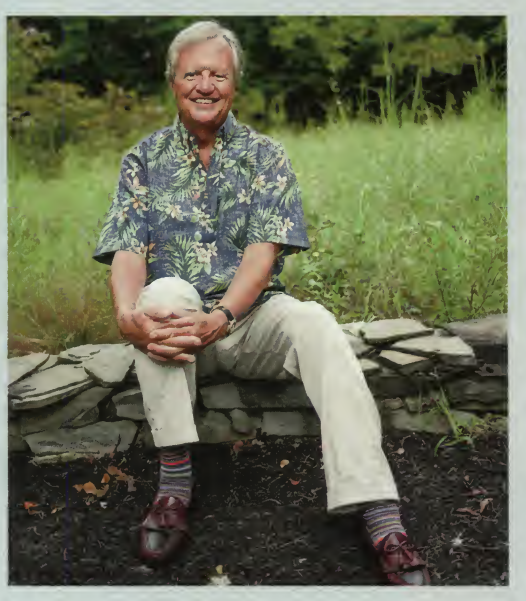
TOP: COURTESY TOM REILLY; BOTTOM: CAROLYN RUSSO/NASM

Jack Clemons

Author of a recent book on space exploration, Clemons was a lead TRW engineer working on Apollo and a member of the mission control backroom team that supported flight controllers on the return to Earth of Apollo missions 11 and 13.

As a contractor, did you have a good working relationship with your colleagues at NASA?
During my 16 years working with NASA on the Apollo, Skylab, and space shuttle programs, I had nothing but good working relationships with my NASA colleagues, who were also my customers. They demanded excellence. They expected results to be complete and on time, and they didn't tolerate excuses. Yet everything was done with professionalism—not nastiness. I attribute

A former senior engineering software manager for NASA's space shuttle program, Jack Clemons is the author of *Safely to Earth: The Men and Women Who Brought the Astronauts Home* (University Press of Florida, 2018). He lectures frequently about human space exploration.



that now to the "failure is not an option" culture that pervaded NASA back then. They expected everyone working on these programs—whether government employee or private contractor—to behave as if he or she wore only a NASA badge.

Based on your experience, did the culture at NASA change over the years?
Apollo's "failure is not an option" culture was still pretty much in play during the early days of the space shuttle program, though some cracks were showing. For example, heat shield tiles on the orbiter's underbelly were breaking off during launch as early as the first flight in 1981, and later NASA decided that since that hadn't caused a problem, it should be considered an acceptable risk. That, I believe, is when the gradual erosion of the culture at NASA began. That "acceptable risk" thinking would ultimately result in the loss of seven astronauts when *Challenger* exploded during launch on January 28, 1986, and the loss of seven more when *Columbia* burned up during reentry on February 1, 2003. Fortunately, NASA's space shuttle culture righted itself after that second loss.

What is your reaction to moon landing conspiracy theorists?
This question comes up from time to time when I'm giving talks about the Apollo program. Sadly, more than a few folks today imagine that, back in 1969, the U.S. government concocted an elaborate hoax meant to fool the Russians into thinking we had beat them to the moon—that the whole charade was clandestinely staged in some remote corner of an Arizona desert. As silly as that is, even my mother, who had followed my adventures for years, once asked me if it was true, because she had just seen on TV that we had faked it. There are numerous independent verifications of the truth of our moon landings—many from sources with no connection to NASA. During my talks, my answer is that 400,000 people, including me, worked on putting men on the moon. Do you imagine all of them could keep this big conspiracy a secret? Furthermore, why would I stand before an audience claiming we did land on the moon when I could make a heck of a lot more money exposing the conspiracy? I know I'm wasting my time—true believers are unpersuaded. But to paraphrase what astrophysicist Neil deGrasse Tyson had to say about science, the good thing is that it's true, whether or not you believe in it.

Read the entire interview at
airspacemag.com/clemons

ANGIE MOON PHOTOGRAPHY

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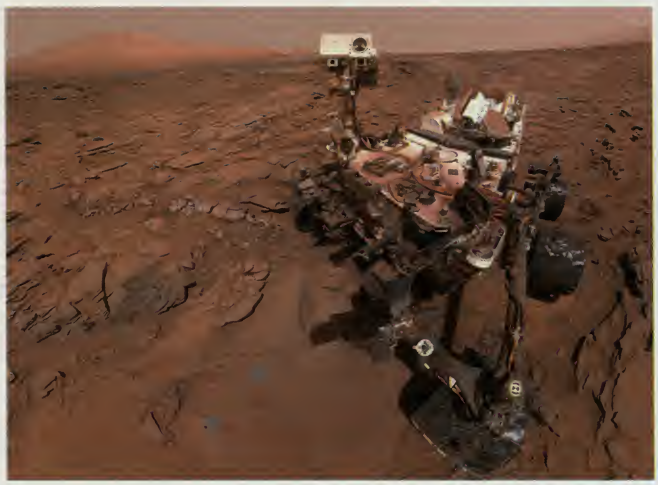
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A HUNDRED SATELLITES, ALL TALKING AT ONCE. HERE'S THE INTEL. **BY HEATHER GOSS**



PLANETS

No Actual Martians...Yet

Scientists reported in June that NASA's Curiosity rover found complex organic molecules that are likely derived from a vast array of macromolecules—the building blocks of life. It's an exciting scientific discovery, the best evidence yet that there was an early ecosystem on Mars. Meanwhile, Curiosity's mission engineers improvised a new drilling technique for the rover, firing up the instrument in June for the first time since October 2016.

UNIVERSE

Magnetic Brakes

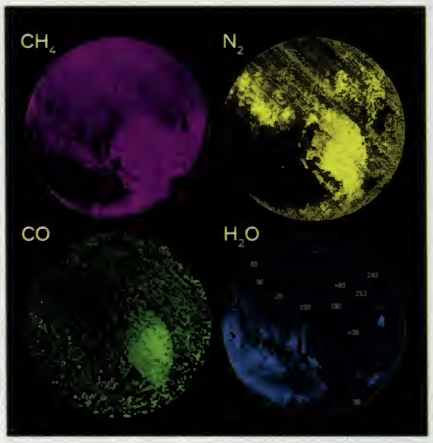
When the Hubble Space Telescope turned to the Eagle Nebula in 1995, it created an iconic image of interstellar gas. Astronomers at the United Kingdom's University of Central Lancashire have recently discovered that strong magnetic fields are running along the Pillars of Creation, forming the unusual structure and keeping it from collapsing into stars.



PLANETS

Pluto's Origin Story?

A new theory is that Pluto formed from the agglomeration of a *billion* comets. Scientists compared NASA's New Horizons' measurements of Pluto's composition (below), especially nitrogen, with data from the European Space Agency's comet visitor Rosetta.





UNIVERSE

A Helium WASP

Astronomers expected to find helium—the second-most abundant element in the universe—in most exoplanet atmospheres, but not until Hubble looked at planet WASP-107b this year did it finally find some. The helium scarcity is a mystery, but the finding proves that spectra will be key to studying exoplanets from the TESS mission (see p. 34)

ROTARY RIDES ON THE RED PLANET

Martian Whirlybirds

When the Mars 2020 rover launches, it will be accompanied by a small autonomous helicopter that will test whether heavier-than-air vehicles can fly in the Martian atmosphere.

IT MEASURES EARTH'S LUMPINESS

GRACE-FO Launched in May

The Gravity Recovery and Climate Change Follow-On spacecraft assumes the mission its predecessor did for 15 years and will test aspects of LISA, a planned gravitational-wave detector.

TOP: NASA/JPL-CALTECH/MSSS; CENTER: SPACETELESCOPE.ORG/NASA/M. KORNMESSER; FAR LEFT: NASA/ESA/HUBBLE HERITAGE TEAM (STSCI/AURA); LEFT: NASA/JOHNS HOPKINS APL/SWRI

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What Keeps Pilots Up at Night

WHEN I WAS LEARNING to drive, I remember how I savored the gently curving descent navigating Ship Road, lit only by our 1986 Saab's headlights. "I love driving at night," I told my dad, in the passenger seat beside me. "It's so much more peaceful." Ever the vigilant instructor, he responded: "That's only because you can't see the dangers at night. They're still there."

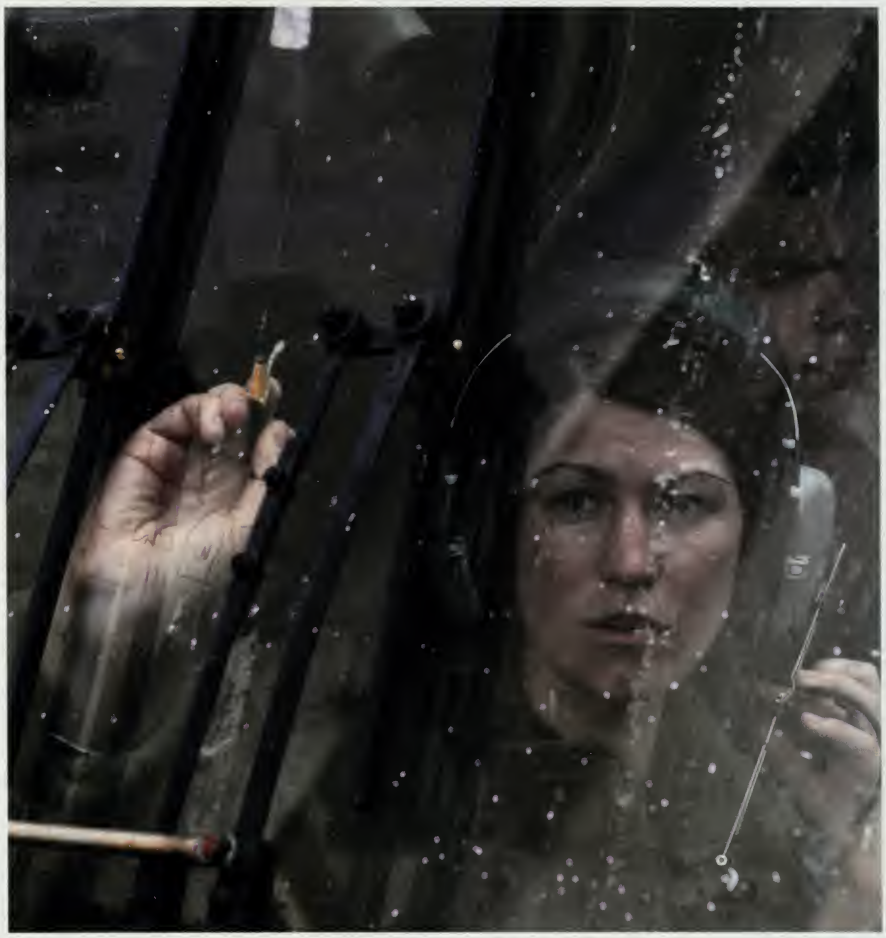
He was a nervous father, but also an experienced pilot. When I started Navy flight school, his words stuck with me.

Human eyes did not evolve toward seeing in the dark. Every pilot learns the basics: Your eyes contain rods and cones. You use your rods at night. Unlike cones, which are concentrated in the center, rods are spread out to the periphery across your eyeball.

Our peripheral vision comes at a cost to overall visual acuity and color perception. There's spatial disorientation, closely followed by its scarier cousin, vertigo. The aviation term for the worst-case scenario that can result from these malefactors is CFIT—Controlled Flight Into Terrain.

Though I understood these hazards, once I'd earned my wings I couldn't help but find night flying as peaceful as those dark Pennsylvania back roads. For one thing, the temperatures in the Middle East, where I deployed twice, are slightly more bearable at 2 a.m. than at high noon. Mostly, it was just quieter: Less chatter on the radios, more shooting stars. The darkness felt like a cloak against unseen dangers. I knew that sense of peace was not to be trusted, but I was grateful for it.

The military trains pilots to recognize physiological degradations to which we're prone at night, but training cannot eliminate our evolutionary limitations. Every pilot has experienced vertigo or spatial disorientation. If you've ever stomped on the brakes as a result of car movement in the next lane at a red light, you've experienced spatial disorientation too.



The author uses a grease pencil to note pallets delivered to a cruiser in the Atlantic, where she deployed with Helicopter Anti-Submarine Squadron Light 46 in 2011.

U.S. NAVY/MASS COMMUNICATION SPECIALIST 2ND CLASS BRIAN M. BROOKS

I saw the 1979 entry in my dad's logbook where he confessed to vertigo on an early training flight: "All you got to do is trust those instruments," he wrote. This mantra is beat into flight students because it does not come naturally.

The first time I remember feeling vertigo was at the end of a flight on my first deployment. Our helicopter squadron would ordinarily practice takeoffs and landings at the end of a mission to keep up proficiency. I landed my SH-60B Seahawk, lining up with the white lines on the gray steel deck with no issues. Time for my next try.

It was nighttime: vertigo risk factor No. 1. It was the end of a three-hour flight. Fatigue: risk factor No. 2. I would "tactically dehydrate" before flights, because there are no bathrooms in helicopters. Dehydration: risk factor No. 3. My takeoff was normal, but maybe I turned my head too quickly to

the right as I simultaneously pulled in power to climb. Multiple-axis inputs to the inner ear, whether you're in a helicopter or on a roller coaster, can send your internal gyroscope spinning.

The pilot sitting next to me spoke up: "So are you planning on turning back towards the boat any time soon?"

I understood what was happening, but I couldn't make my hands move the flight controls. The aircraft's attitude gyro showed us wings level, and the altitude hold was engaged, so we weren't in immediate danger. But I felt my insides flip-flop. "Feel like—already—in a turn," I sputtered.

"I have controls" came the reply. I relinquished my sweaty grip on the cyclic stick, scanning my instruments as the other pilot turned us back on profile—a simple maneuver that felt like a barrel roll to me—to land on the flight deck and call it a night.

While technology has not yet defeated the false sensations experienced by pilots throughout history, it has helped us compensate for our human inadequacies: tools like altitude hold, Night Vision Devices (NVDs), and various collision avoidance systems all help us regularly cheat death.

I have a love-hate relationship with NVDs. They "turn night into day," we're told, which is true if during the day you see only shades of green and black and your field of view is limited to 40 degrees through two separate toilet paper tubes. There is also the weight of the goggles, which causes neck strain. They're mounted on the front of your helmet, and a battery pack attaches to the back. Sometimes there's a counterweight added to the battery pack to keep the goggles from slipping. The rig weighs more than two pounds, which doesn't sound like much, but I challenge you to balance a bag of flour on your head for three hours and move your head constantly. Hot spots may also develop from your helmet, and you can get headaches if your focus is off by even a little.

The alternative to NVDs is spatial disorientation or worse, and goggles may have saved me one night just outside the Arabian Gulf. We usually donned NVDs for the takeoff from the boat, but then I customarily asked the crew to take them off until landing for my own comfort. Either the entire crew wears NVDs or no one does, to prevent confusion. After weeks of patrolling the same square of ocean, we all believed there was nothing out there for us to see.

Either the entire crew wears NVDs or no one does, to prevent confusion. After weeks of patrolling the same square of ocean, we all believed there was nothing out there for us to see.

I might have interrupted my crewman sneaking a nap in the back when I shouted something about an aircraft directly off our nose. I announced a descent to avoid a collision and bottomed the collective control, setting a hard deck of 500 feet. Once we leveled off and my breathing slowed, my copilot and I realized I had dumped altitude to avoid the mast-lights of a container ship. At sea level, obviously.

I'd fallen prey to spatial disorientation, specifically autokinesis, the perception of fast motion in a distant, stationary (or slow-moving) light source. In letting my bored gaze focus on a single light source at the center of my vision, I had enabled the light to appear to move. Forewarned, it turns out, does not always equal forearmed.

Between the training and the tools, U.S. military pilots should be masters of the night skies. Before every flight we brief the same checklist items. When we get to "Vertigo/Spatial Disorientation," every Navy helicopter pilot recites something close to this: "If any crew member even thinks they have vertigo, confess it. If it's the flying pilot and we're in a critical phase of flight, swap controls. If both pilots have vertigo, engage altitude hold and both verbalize control inputs. For spatial disorientation, if anyone is at any time unsure of where we are or what we're doing, speak up and we'll discuss it as a crew, using all the tools we have available to us: instruments, charts, radar, checklists, until we get our situational awareness back."

CFIT is harder to brief or plan for, since it is the result of a chain of sensory illusions. On the wall of some flight briefing spaces you'll find a sign that lists the basic rules of flight:

1. Try to stay in the middle of the air.
2. Do not go near the edges of it.
3. The edges can be identified by objects such as trees, buildings, cars, etc.

The levity of the expression belies the gravity of the message. On the day of my first flight in a Navy aircraft, another aircraft in my squadron flew into a mountain in northern Alabama. Both student and instructor were killed.

With all of the technology and training available to us, the best way to avoid crashing a perfectly good aircraft at night is to have your confidence shaken early. Not destroyed, but shaken. Just enough to remind you to trust your instruments. And when you land, after one of those inevitable scary flights where you couldn't trust your senses, remember to tell Dad he was right.

NICOLE SCHERER

A B-17 Came to Roost in Oregon

THE ONLY THING STRANGER than the sight of a Boeing B-17G parked above a Milwaukie, Oregon gas station is the story of how it got there.

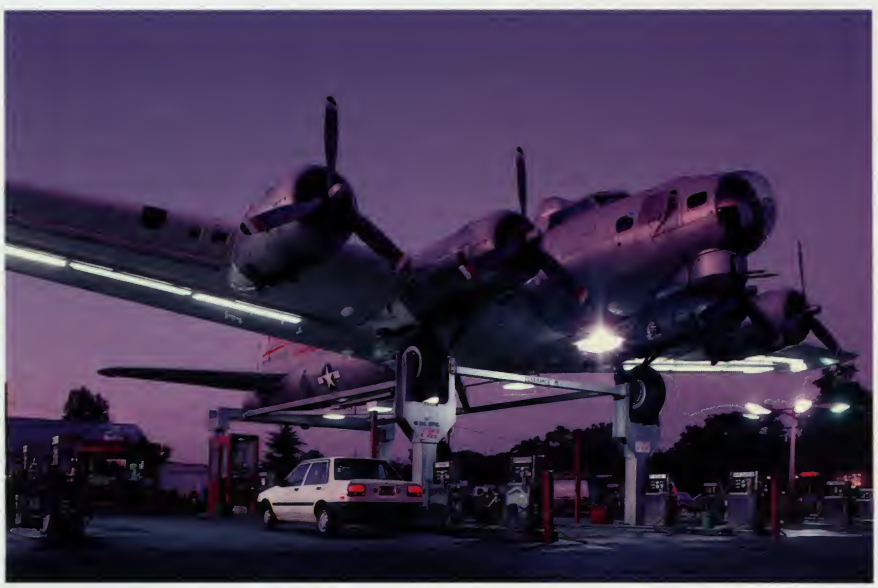
In February 1947, gas station owner Art Lacey announced that he planned to buy a mothballed bomber to attract—and shade—customers. A friend bet him five bucks that it would never happen. "If you told my dad he couldn't do something," his daughter Punky Scott says, "then he was going to do it." The story of how he did it has been Lacey family lore for 70 years.

Lacey borrowed $15,000 and hightailed it to the airport that very night. At Altus Army Airfield, Oklahoma, he bought a well-used B-17 for $13,750. Although Lacey was an experienced pilot, he had never flown anything with more than one engine. But after a few taxi runs, he felt confident enough to take a test hop.

Everything went fine until it came time to land. The landing gear refused to extend, so Lacey bellied in and slid into a second B-17. Fortunately, the War Assets Administration officer took pity on him, and declared it "the worst case of wind damage I've ever seen." Then he sold Lacey another B-17 for a mere $1,500.

This time, Lacey summoned two friends with B-17 experience to help. They arrived with a case of whiskey—Oklahoma was a dry state at the time—to barter for fuel (which base firefighters siphoned from other mothballed bombers). After a stop in Palm Springs, California, where Lacey wrote a bad check to cover refueling, the crew ran into a blizzard.

Visibility was miserable. Lacey slithered into the front turret so they could fly IFR—I Follow Railroads. This worked well until Lacey saw, through a break in the clouds, that they were about to hit a mountain. The crew barely cleared the obstruction.



In 1985, *Lacey Lady* was great for business; today it's hangared—mostly. The top turret, donated to the Commemorative Air Force, flies on the B-17 *Sentimental Journey*.

Eventually they reached Portland but hit another problem after landing: Lacey couldn't get a permit to truck the big airplane to Milwaukie. He disassembled the B-17, loaded it onto four flatbeds and hired funeral-procession motorcycle escorts to give the operation a patina of legality. As a backup, he also paid some hot-rodders to join the parade.

"He told them, 'Do not stop for anything,' " says his grandson, Jayson Scott. " 'If anybody gives you a hard time, you peel out and burn rubber in different directions, and I'll pay all of your tickets.' " Lacey got off lightly, with a $10 fine for transporting the airplane without a permit. The B-17 *Lacey Lady* became a landmark on Highway 99E leaving Portland.

Lacey Lady did the trick, and customers flocked to the gas station. Over the years, visitors stole virtually everything that wasn't bolted down. The wooden floorboards were replaced seven times, before a young boy fell out of the B-17, prompting a lawsuit that shuttered the bomber in the late 1950s.

By the time Art Lacey died in 2000, the airplane looked forlorn. The rainy northwest is not kind to unprotected airplanes, and the B-17 proved an attractive nesting place for local birds. The nose section was removed in 1996 for a restoration project, which stalled when cash ran short.

In 2006, the family created the non-profit B-17 Alliance Foundation to do the job properly. *Lacey Lady* was taken apart and trucked—with a permit—to Salem, Oregon. Jayson Scott figures it will take $10 million and 10 years to get the airplane back in the air. Long odds, but considering his grandfather's record, you might think twice before betting against him.

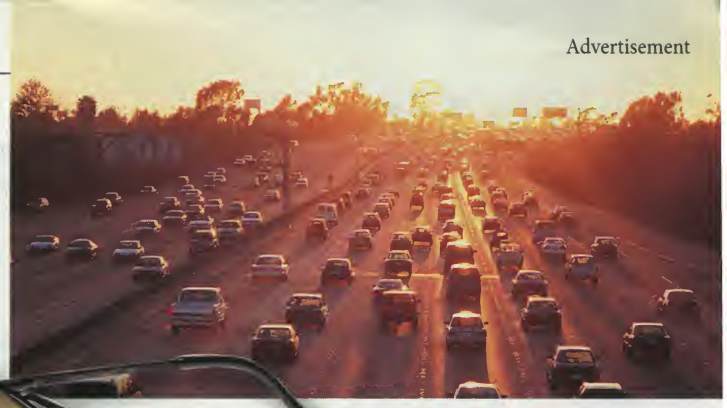
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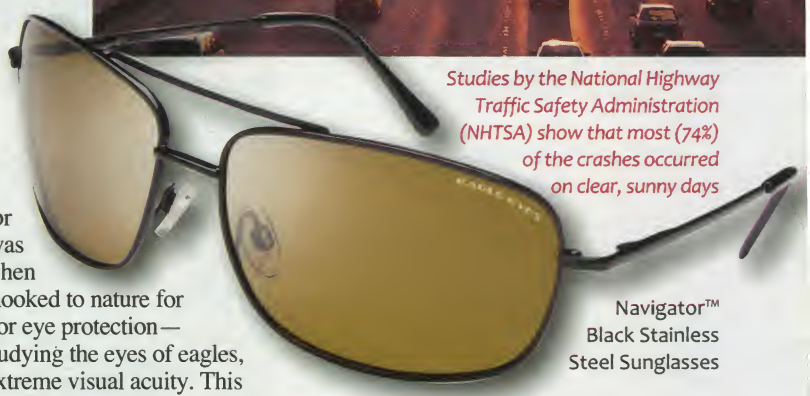
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Night Stalker



Visitors to the National Air and Space Museum's Steven F. Udvar-Hazy Center can see the restored Heinkel He 219—unassembled, but still awe-inspiring.

IN 2012, DANISH DIVERS pulled the badly corroded wreckage of a Heinkel He 219 from the waters off the Jutland peninsula, where it had been submerged since World War II. It was a remarkable find: No more than 294 of the night fighters were built for the Luftwaffe, and before this discovery, there was only one known survivor, which is in the collection of the Smithsonian National Air and Space Museum. The Museum's He 219 was one of dozens of enemy aircraft presented to the United States after World War II by U.S. Army Air Forces commander Henry "Hap" Arnold.

In 1945, three He 219s—along with other captured German aircraft—were shipped from Europe to the United States aboard the HMS *Reaper* and then flown to Freeman Army Airfield in Indiana for testing.

The Museum's He 219 arrived at what was then the Smithsonian's National Air Museum in early 1949. It was reasonably intact but lacked one important item: its nose-mounted intercept radar.

The radar made the He 219 a successful night predator. Once the aircraft intercepted a foe—by homing in on radar emissions resulting from security lapses, for instance—it fired one of its 30mm cannon, installed at such an oblique angle that the 219 could fire from behind and below a bomber, attacking its vulnerable underside. A heavy bomber could be dispatched with just three rounds.

While early versions of the aerial intercept radar installed on the He 219 could be blinded by chaff, later versions were immune. The combination of aircraft and radar proved so formidable that, by early 1944, Royal Air Force bomber losses were as high as 12 percent on some raids.



A British-captured Heinkel He 219 bearing its nose-mounted radar array, circa May 1945 in South Jutland, Denmark. Luftwaffe night fighters had unprecedented success tracking RAF aircraft.

IN PHOTOGRAPHS of the three He 219s at Freeman Army Airfield, all of the aircraft have their antenna arrays. It's not clear why or when the radar arrays were removed, but the missing antenna masts posed a problem for the restoration specialists at the Museum. When they began restoring the He 219 a decade ago, they weren't sure how to fabricate the missing masts.

"We had a lot of pictures," says project lead David Wilson, "but none of them were very good. We couldn't come to an agreement on exactly how the antenna masts were made." (While the antennas themselves are universal, the masts that attach the antennas to the airframe are not; they are built specifically for each aircraft type.)

"The masts are curious," says

TOP: CAROLINE SHEEN; BOTTOM: NASM (SI-2006-20931)

Rob Mawhinney, a specialist in the Museum's restoration shop. "There's no documentation on who built them. They're not in the spare parts handbook for the Heinkel 219, and they're not in the spare parts book for the radars, because they are unique to each airplane. There had to be teams that specialized in making the masts for different airplanes. But none of that information has surfaced."

The shop contacted various archives hoping to find more information; Mawhinney even went to Germany hoping to find something about the masts in Ernst Heinkel's papers but came up blank. "I was starting to give up," he says. "Then we heard about the Danish wreck."

"When I saw the photographs of the wreckage," says Mawhinney, "I was seeing blue wire everywhere. That's radio cable. Somewhere at the end of that cable had to be a piece of radar mast."

The wreckage, originally examined by the Aalborg Defence and Garrison Museum, was subsequently purchased by a museum whose owner wishes not to reveal its identity. Last year, the new owners of the 219 wreckage agreed to loan the radar array to the Museum's restoration shop. "It was like Christmas morning when we unpacked the loaner masts," says Mawhinney.

But there was still a problem: The masts, which had been underwater for nearly 70 years, were covered in coral deposits, and the electrical junction was obscured. The shop X-rayed the masts but needed more information than the X-rays could provide.

They obtained permission from the loaning museum to remove the coral in order to see how the mast was constructed and wired. "After getting nowhere trying mechanical methods of removing the coral," says chief conservator Malcolm Collum, "I ended up using a mild acid solution and ran an electric fish tank pump to keep a constant flow of the solution over the coral." Several weeks later, enough detail was exposed that the team could reverse-engineer a replica antenna.

"Then we reached another stopping point," says Wilson. "We didn't have the mast attach points. What they sent us didn't have the piece that attaches the mast to the airframe. But Rob took some detailed pictures of our aircraft, of where they should be." These photos were sent to the owners of the Denmark wreck, with the request to look at the airframe in a specific location, and, sure enough, the attach points were there. Using a 3D scan provided by the loaning museum, the National Air and Space Museum was able to print a mold of the attach points.

The restoration has revealed other information: "Every component—each vertical, the horizontal itself, the rudder, each aileron—has a serial number tag that indicates the factory where it was manufactured," says Wilson. "And we discovered that every component was made at a different location and then sent to the main factory and put together."

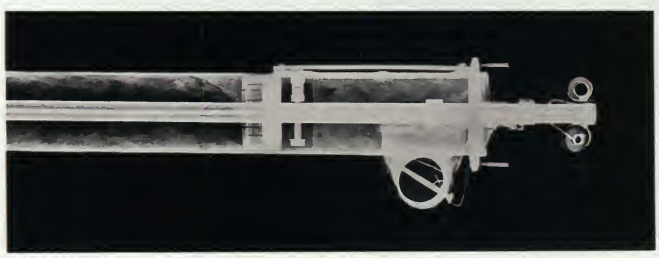
The unassembled He 219 is currently on display at the Museum's Steven F. Udvar-Hazy Center. If all goes well, in about a year the aircraft will be put back together. "It's one that the whole shop would like to finish," says Gary Gordon, one of the Museum's restoration specialists. "Even volunteers who are retired want to come back and work on this."

When it's complete, one of the most feared fighters of World War II will again have the component essential to its reputation.

REBECCA MAKSEL

For more about World War II night fighters, order the new *Air & Space* collector's edition, *World War II in 65 Airplanes*, p. 6.







The Museum's restoration team was able to reverse-engineer a radar array using information gathered by X-ray (bottom) from a loaned coral-encrusted dipole (below). Applying German *Wellenmuster* camouflage to the wing (below, right).

FAR RIGHT: JON BARRETT; TOP AND BOTTOM RIGHT: NASM CONSERVATION UNIT

I LOVE MY JOB AND HERE'S HOW I GOT IT

Hands on History

Chris Reddersen, Museum Specialist, Restoration, National Air and Space Museum

Reddersen and colleagues are currently working on a Lincoln-Standard H.S., a three-place version of the World War I trainer, the Standard J-1.

The job: Reddersen has helped restore some of the most famous aircraft in the National Air and Space Museum collection: the *Spirit of St. Louis*, the Bell X-1, and the Martin B-26 *Flak-Bait*, the medium bomber that flew more missions over Europe—207—than any other U.S. airplane.



Museum specialist Chris Reddersen, holding a *Spirit of St. Louis* model that he and his dad built while Reddersen was in elementary school, got to work on the real thing as a volunteer at the National Air and Space Museum.

Typical day: Although there is no typical day in the restoration hangar at the Steven F. Udvar-Hazy Center, Reddersen says, his days have recently begun the same way: "I walk in nice and clean and within three to five minutes of working on the airplane, I'm coated head to toe in sawdust. For the past couple of weeks, I had been making new ribs for the horizontal stabilizer [of the Lincoln-Standard], but I've transitioned to using a router [on one of] the spars for it."

On *Flak-Bait*, Reddersen did very different work. "We did a total tear-down of the engines, pulled the cylinders off, pulled all the gearing out, and treated all of the corrosion that had developed inside the engine. The engines looked like boat anchors. We dug pounds of grit out from the cylinder cooling fins. We have some magic chemicals that we've been given by conservation; they form a stabilizing layer in the pits the corrosion has formed.

"Most people in my field have done things when they were teenagers like take apart a lawn mower engine or something. I joke with my friends that the first engine I ever took apart was an 18-cylinder radial."

How did you become interested in restoring historic airplanes? "I was about 8 years old when my dad took me to an open house at the Museum's Garber [Restoration and Preservation] facility [in Suitland, Maryland]. I vividly remember that when we were looking at the Seiran Japanese floatplane, I thought, 'Oh, that is the coolest thing in the world.' I knew at that exact moment that the only thing I ever wanted to do was work on historic airplanes."

He also watched all the re-runs of the 1970s TV series *Black Sheep Squadron*.

A&S QUIZ

City living—and flying

How many props drive the first piloted multicopter?

THE GERMAN COMPANY VOLOCOPTER has created a 16-propeller, vertical-takeoff-and-landing, electric air taxi prototype. Its inventors and other designers say that distributed propulsion is the key to electric airplanes. See "Green Skies," p. 60.

LAUREN HORELICK/NASM

The path: After getting a degree in aerospace engineering from Virginia Tech, Reddersen contacted "every airplane restoration place I could think of asking, 'How do you get into doing this?' " Then at a meeting of the local chapter of the Experimental Aircraft Association, he met Anne McCombs, who works in the Museum's restoration shop. She arranged to bring him on as a volunteer on the crew that dusted and cleaned airplanes on display.

"And because I was unemployed," Reddersen says, "I could basically volunteer 40-plus hours a week. I was just trying to build up skills so I could make myself more useful to the organization. I managed to display an aptitude" and got to work with staff on restorations. "They kind of took me under their wing. I spent the better part of two years as a volunteer."

Did you have the feeling that if you just hung in there long enough, you'd get a job there? "I felt so completely blessed to have gotten as far as I had that I didn't allow myself to think that much about it because I didn't want my hopes to get let down if something didn't work out."

Skills needed for the job: "For the Lincoln-Standard, an ability to teach yourself the way things were done in the past. All of the woodworking repairs that we're doing were the general practice for repairs in the 1940s. We're doing seemingly thousands of standard scarf joints [end-to end joints, used in this case to install pieces of wing ribs]. In order for it to be an aviation-grade scarf, you have to do it at a certain angle, and that standard was determined back in the '20s, '30s, '40s.

"It's hard to believe that [the airplane] first flew about 100 years ago. That is a really cool thought."

Best thing about the job: "I love the human touch in all of these artifacts. That's what draws me to restoration: being able to connect to people who came before me. It's such a small thing, but one of my favorite things that I've seen on any project was on *Flak-Bait*. On the inside of one of the exhaust panels, I found someone's thumbprint that was etched into the back of the aluminum. And I'm just figuring this probably happened when this mechanic was out in the field and he pulled off this panel. It was still hot and he touched his thumb to it by accident. So he may have been saying some swear words, but for me finding that evidence of this person working on the airplane before me.... There have definitely been a couple of moments when I've gotten chills.

"And in what other job can you make the statement: *Darn it. I can't get to the sewing machine because the machine guns are in the way?*"

INTERVIEW BY LINDA SHINER



Reddersen, working on the Lincoln-Standard wings, says he owes a tremendous amount of gratitude to Museum coworkers who have taught and mentored him.

SCOTT WILLEY

UNBELIEVABLE. BUT TRUE!

The Cool Side of Tropical Warfare

Another reason U.S. Marines loved Corsairs.



BY LATE SEPTEMBER 1944, the men of U.S. Marine fighter squadron VMF-122 were stuck on Peleliu and bored. Their F4U Corsairs were only 10 minutes' flight time from Japanese-held islands, but the enemy, cut off from their supply lines, posed no aerial threat. As squadron commander J. Hunter Reinburg recounted in his autobiography *Combat Aerial Escapades: A Pilot's Logbook*, he told a reporter, "This dive-bombing and strafing just isn't as exciting as dogfighting, but the damn Japs won't come up and fight."

Reinburg, determined to raise morale on a humid tropical island with no fresh food and no refrigeration, had a plan. His maintenance crew cut the ends off an old belly-mounted drop tank, strung wire at both ends, and mounted an access panel to the side. Into this panel, secured by the wires, went a waterproof can that ordinarily stored .50-caliber bullets. And into that, the mess sergeant poured a mixture of canned milk and cocoa powder. Reinburg planned to ascend to high altitudes, where temperatures are well below freezing, and return with a gift for his men: Five gallons of homemade chocolate ice cream.



After lifting off on what he logged as an "oxygen system test," Reinburg circled at 33,000 feet over Japanese-held Palau, watching anti-aircraft batteries—useless over 28,000 feet—waste irreplaceable ammunition trying to hit him. After 35 minutes of fireworks, he returned to Peleliu with a disappointing cargo. The mixture was cold but not frozen (the squadron scarfed it anyway), a failure the crew chalked up to its proximity to the hot engine.

For the next attempt (a "supercharger test flight"), they bolted ammo cans to the underside of a removable maintenance panel on each wing, well away from the engine—doubling their yield to 10 gallons, enough for 100 men. This time the mixture froze. The squadron again devoured it immediately. But the ice cream was too flaky for Reinburg's taste, so his crew modified the ammo cans with small propellers: The wind turned the propellers, which drove a screw inside the can, churning the mixture. The result, finally, was a smooth, creamy chocolate ice cream.

Operation Freeze flights soon became routine, rotated between the squadron's pilots and airplanes. They went off without a hitch, wrote Reinburg, until his boss, group operations officer Colonel Caleb Bailey, called to make clear that he didn't buy the "test flight" ruse. "Listen, goddammit, you guys aren't fooling me," Bailey told a VMF-122 officer. "I've got spies. You tell [Reinburg] I'm coming over there tomorrow and get my ration."

Reinburg's Marines were not the only ice cream-makers of the war. B-17 crews in Europe brought ice cream mixtures along on operational bombing raids, according to a 1943 *New York Times* article, and at least one unit used its P-47s to create a real delicacy, vanilla ice cream mixed with canned fruit.

ZACH ROSENBERG

The Vought F4U Corsair was a multi-role aircraft: fighter, ground attacker, and ice cream maker. Left: In 1945, a Navy pilot enjoys the store-bought version of what Marines made for themselves.

TOP: HANS GROENHOFF COLLECTION/NASM (HCG-1448); BOTTOM: US NAVAL INSTITUTE

A&S|NEXT

Let us hear from you! Have you just soloed? Started a new job? Finished an internship? Invented an aeronautical gadget? Tell us about your experience, and send us a photo. ***editors@si.edu*** or ***facebook.com/AirSpaceMag***



SHARK SPOTTER

A new database helps track sharks by air. BY CHRIS J. BAHNSEN

AFTER GETTING REPORTS FROM SURFERS of sharks in the vicinity of Seal Beach, California in 2015, chief lifeguard Joe Bailey became the first lifeguard on the West Coast to use drones for shark patrols. When he and his crew flew a DJI Phantom quadcopter with built-in video camera over the ocean, Bailey told a local news station that within 10 minutes, "We knew there were 10 to 12 sharks all in the Surfside [Beach] area."

Other lifeguards soon followed his lead, and so did Chris Lowe, director of the Shark Lab at California State University, Long Beach. Lowe began using Phantoms to survey great white newborns and yearlings, born in nurseries off SoCal beaches. But there's also a problem with using drones as shark spotters: From an altitude of about 100 feet, the drone is not getting clear imagery of what's swimming underwater, and it can be challenging for the user to tell if that blob on the screen is a shark or something else. "We have water that has a lot of turbidity, and so if the shark is deeper than three or four feet, we can't see them," says Bailey. "And it's sometimes difficult to tell how big that shark is."

So Lowe is now hoping to return the favor—with software that could help lifeguards use drones more confidently.

"Right now, we're looking to work with computer scientists and engineers to develop artificial intelligence—search engines that can go through and decipher what those blobs may be," says Lowe. He hopes to find partners to create software that will give lifeguards a probability rating, based on criteria such as the shape of the object and how it moves. "Initially, it might give you a 75 percent total confidence that the blob is a white shark. And then, the more footage we gather, the more the software trains itself to refine its algorithms," Lowe says.

Lowe's Shark Lab has also just invented a shark app for iPhones and iPads, designed for agencies that patrol SoCal's sharky beaches by air. The lab recruited computer science students at CSU, Long Beach to design the software and develop the cloud database. "It's meant for sheriff, police, and Coast Guard helicopter pilots," says Lowe. "So, while they're flying, if they see some sharks, they can just hover over, take pictures and video, and dial in some numbers: What species do they think it is? How many sharks? The app info is then automatically loaded into a database."

Shark Lab will train the pilots to better identify sharks and estimate their sizes so that entered information is as accurate as possible. Over time, this database will be calibrated and spatially mapped to serve as a resource for research.

In the meantime, lifeguards are implementing the "shark policy" Lowe helped them develop, such as when it's advisable to close a beach. Based on current trends, the guards don't expect the "men in gray suits," as surfers call sharks, to leave any time soon.

Conservation efforts and an increase in seals have led to more sharks (below) and therefore more drones (above) near beaches.



TOP: STOCKSTUDIO/SHUTTERSTOCK.COM; BOTTOM: MARTIN PROCHAZKACZ/SHUTTERSTOCK.COM



THE ROAR AND CONCUSSION WERE STARTLING. Clocked at 554.69 mph, the ultra-modified P-51 racer *Voodoo* shot by and was gone. Its first pass over the three-kilometer straightaway took 12 seconds.

I was watching air racing superstar Steven Hinton attempt to do what his father had done 38 years before: set the three-kilometer speed record for piston-engine, propeller-driven aircraft. For raceplane pilots, the three-kilometer record (1.86 miles) is an Olympian goal, captured by the greatest pilots in history. "This record has been around since the beginning of aviation," says the younger Hinton, pointing out that the fastest jet record wasn't established until almost 1950. "It connects the generations."

He mentions Jimmy Doolittle, who set the record in 1925 flying a Curtiss seaplane, one day after he won the Schneider Trophy for the United States. Eight pilots, including Amelia Earhart, beat Doolittle's record, but he won it back in 1932, flying the storied Gee Bee R-1 at the Cleveland National Air Races. After World War II, a fascination with jets pulled the focus away from the piston-engine record, and it slept for 30 years. In 1969, air race champion Darryl Greenamyer decided that 30 years was long enough for the record to be held by a German Messerschmitt. His modified Bearcat *Conquest 1* brought the title back to the United States and earned the Bearcat a place in the National Air and Space Museum.

World's Fastest Piston-Power Airplane

A star team led by a racing phenom grabbed the record. But there's one left to break.

STORY AND PHOTOGRAPHS BY SCOTT GERMAIN



You can almost hear the Merlin growl as the Mustang *Voodoo* is prepared by its team to make history. Pilot Steve Hinton (right) has worked for years toward this moment.

Last September, Hinton was chasing the record set a generation later, in 1989, by another famous pilot, Lyle Shelton, in another famous Bearcat, *Rare Bear*. The massive racer, built from a wreck, had been perfected over two decades of competition. Some thought Shelton's speed—528.31 mph—would never be beaten. And according to the Fédération Aéronautique Internationale, the body governing worldwide aviation competition, it won't. The FAI database states that Shelton's record



The crew can learn a lot from running *Voodoo*'s Rolls-Royce Merlin V-12 at night. If compression is low in a cylinder or a spark plug isn't firing, they will see evidence in the exhaust flame. The color of the flame also indicates whether a cylinder is getting the optimal fuel-air mixture.

has been "retired by changes of the sporting code." But Art Greenfield, of the U.S. National Aeronautic Association, says the FAI statement is wrong, and he wants the international organization to correct its database. "We changed the rules, but we did not want to change history," he says.

Greenfield, the NAA director of contests and records, explains that when Shelton set the speed record, he wasn't required to specify the weight of the airplane; his speed was entered in the NAA database in an "unlimited" category. Today, a challenger must specify one of 23 categories determined by an airplane's takeoff weight; if a record is set, it applies to that weight class alone. There is no longer an unlimited category. But, says Greenfield, if a challenger flies at a speed one percent faster than Shelton's 528.31 mph, Shelton's name will disappear from the record list. Until that happens, Shelton stays. His record is there to beat.

Modified racers like Mustangs and Bearcats fall in the category weighing between 3,000 and 6,000 kilograms (about 6,600 to 13,200 pounds). In that category, the first to set the record under the new rules was Will Whiteside, flying a modified Yak-3U, *Steadfast*. In 2011, he hit 416 mph, a tremendous speed for a Yak but nowhere near what Bearcats like *Rare Bear* and Mustangs like the current Reno champion *Strega* can do. Topping 416 would be easy. But Steven Hinton—Stevo, as he's called by friends and fans to distinguish him from his famous father, also named Steve—was aiming higher.

The younger Steve Hinton (he is not a junior; father and son have different middle names) was born into warbird royalty. His grandfather Ed Maloney, who in 1957 founded the Planes of Fame Air Museum in Chino, California, was one of the first to recognize the historical value of World War II airplanes, and he did more to preserve them than any other single collector in the country. In a story that every race fan knows by heart, the senior Hinton was best friends from second grade on with Maloney's son Jim, and the pair knocked around the museum as kids and became pilots and precocious warbird experts together. (They also became family when Hinton married his friend's sister Karen.) Jim Maloney died in an airplane crash in 1983; Hinton became a fixture at the National Championship Air Races in Reno, winning Unlimited Gold in 1978 and 1985 and, in 1990, taking over from the legendary Bob Hoover as the Unlimited pace plane pilot, the one who sets the pace for the formation of racers as they enter the course. The younger Hinton entered racing as a crew member on *Strega*, Bill "Tiger" Destefani's hot-rod Mustang, and in 2009, as *Strega*'s 22-year-old pilot, became the youngest person in history to win an Unlimited Gold race. (There is no longer an unlimited category in speed records, but that has nothing to do with the Unlimited racing class, for piston-driven airplanes weighing more than 4,500 pounds.)

When he was 15 or 16, Stevo Hinton says, he found in the attic his dad's three-kilometer speed trophy. "That was about the same time I got bit by the air racing bug real hard," he remembers. He started reading about the speed record, researching its history in the Planes of Fame museum library. "It made me a more goal-oriented person," he says. Learning about it made

TOP: JARROD ULRICH; BOTTOM: AIR RACING HISTORY

THE FASTEST PISTON-ENGINE AIRPLANES



1939, Messerschmitt Me 209, Fritz Wendel, 469 mph
The 209 was a unique aircraft, built to break the record.

him think "This is something I really want to do." He kept the old trophy on a shelf in his bedroom, a daily reminder of a goal he wasn't sure would ever be within his reach.

A Horse of a Different Color

"When they designed these planes back in the '40s, they didn't have any of the computational fluid dynamics [CFD] tools we have today," says Danny Sikavi, chief of aerodynamics for Aviation Partners, a firm that designs and installs wingtip devices, or winglets, on corporate jets and airliners to make them more fuel efficient. Sikavi's team used CFD software to analyze *Voodoo*'s airfoils. He says, "It was getting pretty strong shocks on both the upper and lower surfaces."

In 2010, when he was still with the *Strega* racing team, Hinton met Aviation Partners CEO Joe Clark. Clark talked to him about sponsoring *Strega* for a record attempt. "We couldn't put it together at the time," says Hinton. "Tiger didn't want to risk his asset for little or no return, which is understandable. Who risks a $2 million asset for nothing but personal satisfaction?"



If hairline cracks form in specialized contact pads, they can cause catastrophic engine failure. Hinton inspected the pads, the valves and lifters, and every other part of the airplane.

As it turned out, *Voodoo* owner Bob Button. But in 2013, when Hinton switched to the *Voodoo* team, the Mustang was not the airplane *Strega* had been. "It flew horrible," Hinton said. "The airfoils on the wing, horizontal, and vertical [stabilizers] were incorrect. The incidence on the tail was wrong. The canopy never fit well. The scoop was old. There were a lot of things I thought we could do better."

From 2013 through 2015, Hinton, transferring all he had learned by working on *Strega*, helped his new team bring *Voodoo* to the sharp edge of piston-engine performance. In 2016, after his third Unlimited win in *Voodoo*, Hinton found that Clark was still interested in sponsoring a run at the record. And Clark had an idea for making the now fast Mustang even faster.

"I didn't want to just throw money at the record," says Clark. "Anybody can do that. I wanted to add value."

Clark's aerodynamicists and engineers went to work.

The shock waves Sikavi found in CFD studies were the result of supersonic airflow over portions of the wing, and they cause abrupt increases in drag. The engineers began to look for ways to weaken the shocks or delay their formation. With computer-aided design and CFD software, they prescribed pressure distribution over the wing. They then created shapes that eliminated or weakened the shock. They maintained the profiles of portions that were shock-free.

"Most of the changes occurred on the wing's upper surface," Sikavi says. "On the lower surface, we were limited to the inner portion of the wing."

The final shape of the airfoils increased the airplane's critical Mach number, the speed at which drag rises rapidly. "In other words," Sikavi says, "we had the same amount of drag from the wing but at a higher airspeed." The modification increased *Voodoo*'s critical Mach from 0.72 to 0.76. That difference may seem small, but it represents a remarkable performance gain: at 7,000 feet, an additional 28 mph on the same horsepower.

The design was made final in February 2017, and Hinton's team, working with Aviation Partners, began the physical modifications for a run at the record planned for July. To produce the



1969, Grumman Bearcat, *Conquest 1*, Darryl Greenamyer, 482 mph



1979, North American Mustang, *Red Baron*, Steven Hinton, 499 mph



1989, Grumman Bearcat, *Rare Bear*, Lyle Shelton, 528 mph

BOTTOM LEFT: TIMOTHY WEINSCHENKER; CENTER: FRANK MORMILLO; RIGHT: DON "BUCKY" DAWSON

most precise airfoil, *Voodoo*'s wings were de-mated, stripped to bare metal, then laser mapped. Using the digital data, Aviation Partners milled 35 carbon-fiber pieces to be applied to the wing to change its shape.

For two weeks of 14-hour days, Hinton and teammate B.J. Healis installed the machined parts at precisely mapped locations on *Voodoo*'s wings with corrosion-inhibiting adhesive and rivets. After the final piece was installed, the team had to fill and smooth the new surface. Then the hard part began: Hinton, Healis, and teammate Ben Marsh, who had worked on *Voodoo*'s wing the last time it was profiled, spent hundreds of hours sanding, refilling, measuring, and sanding again. Once the work was complete, the wing was painted, clear-coated, polished, and re-mated to the fuselage.

As the modifications were getting under way, Joe Clark requested another big transformation for the racer. *Voodoo* lost its garish purple, orange, and green race paint and emerged at the end of the summer wearing a classy, creamy white. (The photos of white *Voodoo* that the team posted on the Internet caused their own shock waves among race fans grown accustomed to the racing livery.) A number of the aircraft Clark's company had used as testbeds had worn white, and Clark and Hinton decided that a white airplane would provide the best billboard.



Andy Chiavetta finishes the induction trunk he built from carbon fiber to limit leakage as it feeds air to the supercharger.

Power and Pressure

As work and planning progressed, the team selected Clark's private ranch and airstrip in Idaho's high country as the location for the attempt. High summer temperatures and a 5,500-foot elevation made the airstrip optimal. For maximum speed, airplanes like the Mustang perform best in thin air at high altitudes. Less dense air nets a higher true airspeed, the actual speed an aircraft moves through the atmosphere (as opposed to indicated speed, calculated by the amount of air molecules entering instruments). High temperature offers additional help for the same reason; hot air is less dense.

The reverse is true when it comes to the engine; less dense air means the engine will generate less horsepower. Fortunately, the supercharger in racing-modified V-12 engines can shove more air into the cylinders, producing wild amounts of "boost," or increased manifold pressure. The internal combustion engine mixes fuel and air; the more air you can pump through the engine (via the supercharger) and the more fuel (via the pump and metered by the carburetor), the more power you can make.

Stock Mustang engines produce 1,425 horsepower at 60 inches of manifold pressure and 3,000 rpm. The supercharger in a racing V-12 can produce up to 140 inches of manifold pressure. For the record attempt, *Voodoo*'s engine produced 3,100 horsepower. (Few of these settings are automatic. Pilots adjust manifold pressure and rpms as they fly.)

Stuffing more air leads to another problem: too much heat. The thermodynamics experts counter the heat with massive amounts of ADI, anti-detonation injection, a 50/50 mix of distilled water and methanol sprayed into the engine.

Air races are rough on engines, and sometimes a race is lost because the engine can't stand up to the demands placed on it. (In 2015, after five laps, engine problems forced Hinton out of the race.) At the 2016 event, Hinton didn't need to use big power to win; nevertheless, after the race, Bob Button sent the engine to José Flores, owner of Vintage V-12s, in Tehachapi, California, one of the most respected engine shops in the country. Flores is a master at building Merlins that will rage around the race course and survive the inferno. A few months after the the Merlin arrived in Tehachapi, the *Voodoo* team sent a second one: insurance against problems with the primary.

The proof that the engine would sustain its power through the four laps of the record attempt would come only during the attempt itself. But to get an indication of how it would behave, the team set up for flight testing.

Early tests showed that the airframe modifications had resulted in significant gains in performance. "The airplane accelerated much faster to the high-speed realm," Hinton says. "At 100 inches [of manifold pressure], I'd never seen a speed that fast before."

Delays in the fabrication of the wing's puzzle pieces and in the laborious application of those pieces had caused the late July window to slip to the last days of August. This schedule shoved the record attempt up against the 2017 Reno air races, to be held only a week and a half later. The crew had previously decided to concentrate solely on the speed record; if they didn't blow both engines, they'd discuss racing at Reno.

Moments of Truth

The nine months leading up to the record attempt had been grueling for Hinton. For much of the final three weeks, I spent days with the crew as they worked, overcame obstacles, and kept their focus on the goal. By that time, Hinton hadn't been home in months, yet despite the long hours, he remained enthusiastic and friendly. Work had started on the airplane the previous December, and from May onward he had led a small team working 16 to 18 hours a day, seven days a week—without pay. The effort was entirely volunteer. His crew was small and skilled; every member was able to do just about any job. Frank Young, a *Voodoo* crew member from its first day of racing, knew every nut and bolt of the aircraft; B.J. Healis, an

JARROD ULRICH



At Joe Clark's airstrip in Idaho, Hinton flies a full-power test pass over the three-kilometer course to measure fuel and coolant consumption before the record attempt.

unparalleled aircraft mechanic, was famous as a team player; Bernie Vasquez, a warbird and race pilot himself, could handle everything from paint and body work to engine work to manning the crew radio and telemetry; Ben Marsh knew *Voodoo*'s wing better than anybody; and Cory O'Bryan, Hinton's friend and former roommate, was an experienced airplane painter. Andy Chiavetta, who had built Darryl Greenamyer's Sport-class winning Lancair and had become himself a fixture at Reno, also helped out.

Hinton managed the operation, and his fingerprints were on every part of the airplane. I watched him checking Merlin Fingers, the custom rocker arms within the engine's valve train, which can develop tiny cracks at race power. The next hour he might be juicing the high-octane racing gas with liquid manganese (that helps prevent detonation) or inspecting the course from a helicopter to pick out landmarks.

In the Reno pantheon, Hinton is a rarity. Unlike most of the pilots who fly the big, expensive Unlimited racers, he's not a specialist brought in only to fly the airplane. He's a warbird mechanic, who learned from old-school pilots and guys with 60-weight oil under their fingernails. "I enjoy the work," Hinton says. "You're trying to figure out what makes these 70-year-old machines tick. If something breaks, you have to understand why it broke. There are no computers to diagnose the problem. It's something that challenges you and pushes you." Hinton was about to get pushed.

The team had measured and marked the course, and *Voodoo* was ready for the record flight. Hinton's father was on hand to pilot a Lockheed T-33 jet, equipped with a new gyro-stabilized camera system provided by Pursuit Aviation. He would also be available to play the role he had played for dozens of pilots in dozens of Unlimited races: If something goes wrong, it's Steve Hinton's voice the pilot hears on the radio, offering advice, talking the pilot through the emergency.

Stevo climbed into *Voodoo*, took off, and made two maximum-power passes to measure how much fuel and ADI were consumed so the team could calculate the minimum needed at race power, plus some reserve, so Hinton wouldn't be carrying unnecessary liquid—and weight. After he landed, the crew measured how much was left in the tanks. The news wasn't good. The engine was flowing too much fuel—so much, in fact, that the airplane couldn't carry enough for the required four passes. The trouble turned out to be a faulty carburetor. A spare was readied and installed, and Hinton took off to test it at high power.

As he brought the throttle up through 100 inches of manifold pressure, the engine violently backfired. A mighty jolt to the airframe was accompanied by belches of smoke from both sides of the engine. Hinton immediately brought the power back and arced to a safe landing.

I could see stress and exhaustion showing in his bearing as Hinton walked away from the airplane. He was trying to hold

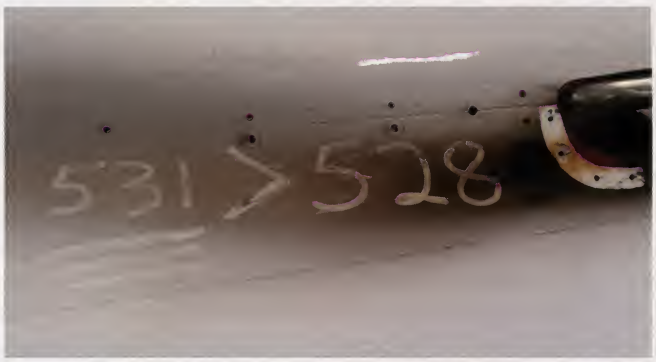
it together; at the same time, he needed to vent his frustration. He fired off an expletive before joining the crew to analyze what had happened.

The engine backfire was serious. The crew tore into the engine and discovered a problem with one of the valve seats, a metal ring against which the valve rests when it's closed. The seat hindered valve movement, and that in turn disrupted fuel flow, causing the backfire. The engine wasn't damaged, but the attempt couldn't be made until the part was replaced. The team deliberated: Should they fix this engine or install the backup? It was a gamble they couldn't afford to lose. After a phone conference with Flores, they removed the offending bank of cylinders and flew it to his shop for repair. The decision was to stick with engine number one; at least they knew what they had.

Three days were lost, and when the repaired bank was installed and ready, August had ended. Weather became the next problem. Smoke from numerous wildfires in the Pacific Northwest had fouled the air and limited visibility to three miles, an uncomfortable limit for a pilot who would be flying at around 792 feet per second. Worse, the meteorologists were forecasting lower temperatures over the next several days. The window for Hinton's attempt was closing.

In the smoky afternoon sun on September 2, Hinton's fiancée Jane Lynch (today, she's Jane Hinton) walked him out to *Voodoo*. Cockpit video cameras and the FAI's tracking equipment were turned on, and, after a few fist-bumps with the crew, Hinton climbed into the cockpit to begin his methodical strap-in routine. The repaired Merlin fired to life, and *Voodoo* taxied out for takeoff.





Top: After the flight, Hinton briefed his father (green flight suit) and airplane sponsor Joe Clark. Bottom: A teammate's graffiti on *Voodoo*'s fuselage. Can't argue with mathematics.

Hinton transmitted to Vasquez from the end of the runway: "I like it."

The telemetry screen in front of Vasquez showed *Voodoo*'s vital signs in real time. Hinton lined up on the runway, pushed the throttle forward, and began his takeoff roll.

"ADI," said Vasquez. "Got it," Hinton replied. *Voodoo* wailed by center field and gently left the ground; Hinton folded the landing gear and banked downwind to begin the attempt. The Merlin's sound trailed off into a muted buzz somewhere in the dull, orange sky.

In *Voodoo*'s cockpit, Hinton was watching the engine vital signs on the instrument panel before him. He was constantly tweaking the ADI with a valve on the panel that fine-tunes the amount of water/methanol mix flowing to the engine. The workload was high; any change in power, speed, or altitude required a small change in ADI. But the pilot was at the top of his game. He had won Reno seven times by flying consistent, machine-like laps and hitting the same piece of sky every time.

After the first pass, Hinton banked right to perform the turnaround, a 2.5-G maneuver designed to balance scrubbing speed without expending too much time, fuel, and ADI. It was a delicate act. With his altimeter and vertical speed needles bouncing wildly at the extreme airspeed, Hinton had to somehow make sense of their readings and stay within the required 1,500 feet of the ground.

The second pass, at 527.34 mph, was almost 30 mph slower than the first; the effect of the entry dive had worn off. The third reached 528.48 mph, then another fade of ungodly engine howl to the west. The crew, watching through binoculars, reported seeing oil—massive streaks of exhaust staining the fuselage sides.

In the cockpit, Hinton knew from the very start that the engine wasn't making the required power. The manifold pressure gauge read 117 inches; it should have been 130 or more.

During the third pass, Hinton caught the oil pressure dropping from 120 to 70 pounds. The drop was a sign that the engine was failing. Vasquez came over the radio a second later with the same bad news.

"I see it," Hinton radioed.

Should he continue the run and hope the engine held together or reduce power and land? Was there an instant when he flashed on the pilots who had pushed hard and crashed at Reno? If he pulled up now, what would all the months of work mean? There wouldn't be enough time to try again.

Hinton banked steeply. Instead of the 2.5-G turn, he pulled 4.5 Gs to head back toward the runway for the fourth and final run. The sharp bank was his decision to get the airplane pointed toward the runway immediately, in case the engine did quit, or worse, blew up. He said later, "Those three seconds were the most intense of the entire attempt."

The higher-G turn scrubbed off a lot more speed; that would hurt the average. The white dot to the west grew into an airplane again as he lined up for the last pass.

As Hinton and *Voodoo* flashed over the runway one final time, Vasquez keyed his mic so the pilot could hear the magnificent sound for himself. "Thanks for that," Hinton replied.

Failing engine and all, *Voodoo* clocked at 515.62 mph on the final pass.

The Final Reckoning

When *Voodoo* was towed inside, it looked beat. After a short time, the FAI observer had crunched the preliminary data and approached the small crowd waiting in the hangar. His announcement: 531.53 mph (later revised to 531.64). *Voodoo* had shattered the weight-class record of 416 mph. The official, knowing that Hinton was gunning for Shelton's record, also noted that Hinton had not hit his goal. A number of us murmured disappointment, but Bob Button, his booming voice filling the hangar, changed the mood: "Hey! We set the record, people!" Button shouted. "We are the fastest piston-engine airplane in the world!"

Gathered around the stained, dripping racer, people began to exchange hugs and the buzz of talk and laughter grew louder. As the celebration gained momentum, a *Voodoo* crew member used his finger to scrawl some numbers in the engine exhaust stain on the raceplane's fuselage: "531>528." Hinton had beaten Shelton's speed.

But not by one percent.

In the decades ahead, many will tell the story, which sounds like a fairy tale, of a young virtuoso who reigned at Reno for almost a decade then reached for his childhood dream. And they will all wince when they repeat the phrase "but not by one percent." But is that how the story ends?

After the record win, Button donated *Voodoo* to the Planes of Fame museum, and recently, as Hinton was reflecting on the record, he said, "There are quite a few things we'd change if we were lucky enough to do it again. We feel like the airplane can go faster. We left some on the table." The magic number of one percent greater than Shelton's 528.31 mph is 533.59. And one percent faster than Hinton's own record is 536.95. "We feel like the airplane is capable of 540," Hinton says.

Hinton, again reflectively, says he's trying to start raising the money that would be required for another run at the record. Interviewing the crew about their 2017 experience, I can guess that it wouldn't be hard to put the band back together. "If you leave something on the table and feel like there's room for improvement," Hinton says, "and have a path to get there...," he trails off.

Is it possible to rewrite the ending of a fairy tale? There may be another entire chapter. Steve Hinton is only 30 years old.



On a peaceful evening before the 2017 Planes of Fame Museum Air Show, the two rivals *Voodoo* and *Strega* sweep across California's Lake Matthews. Title-holder *Voodoo* leads, but in the next matchup, positions could change.

OUR NEW **PLANET** HUNTER



Around one of 20 million stars, TESS will find something that looks like us. BY REBECCA BOYLE

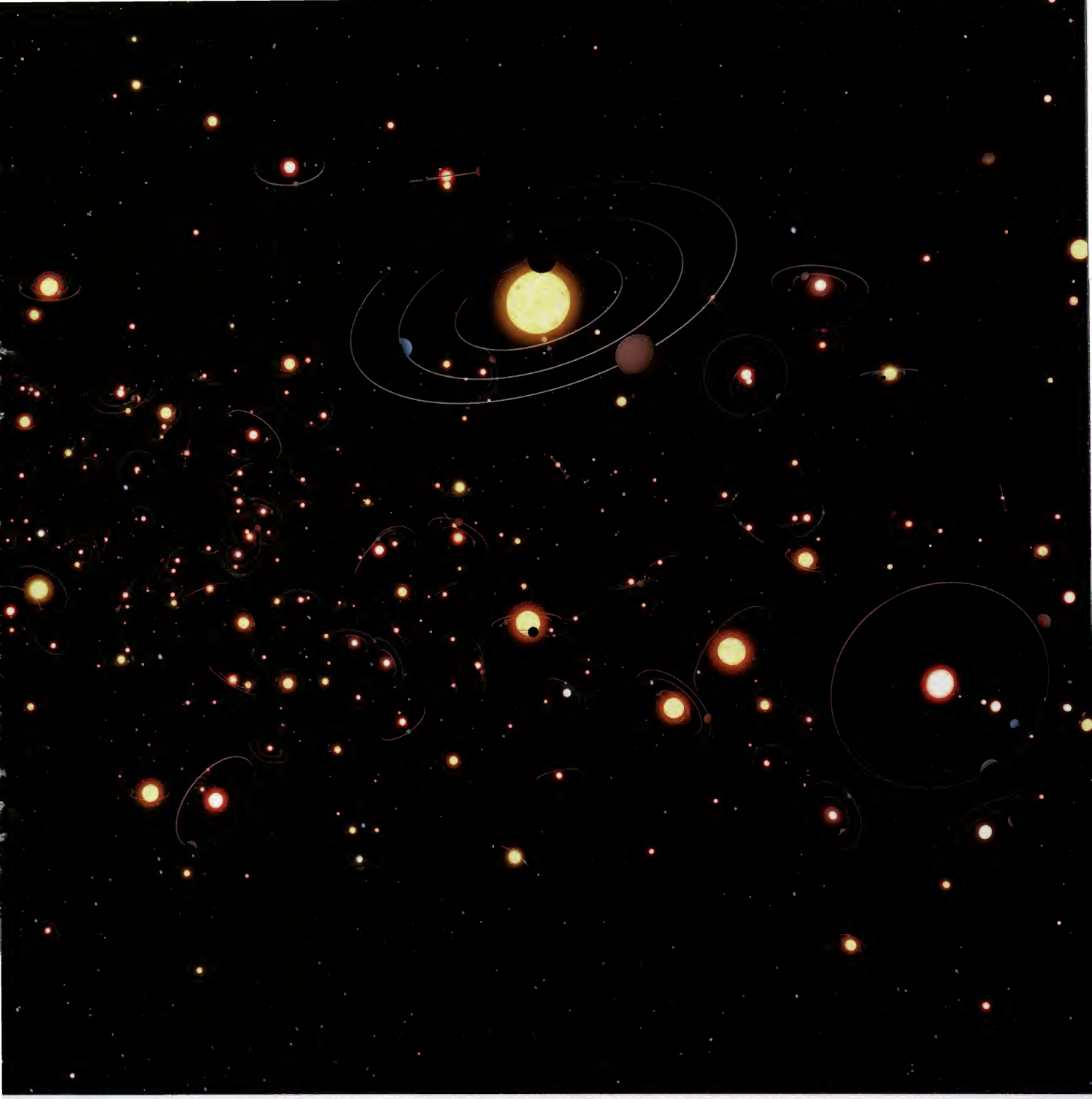
THE NEXT GENERATION of humans will see the night sky entirely differently from the way we see it today. Even in cities, where the glare of lights drowns out all but the brightest stars, people will be able to look up, locate a distant sun, and describe the alien worlds that orbit it.

Giant telescopes on frigid mountaintops will have scrutinized those worlds, helping astronomers discern their sizes and basic compositions. A telescope orbiting Earth will have peered into their atmospheres, and may have found signs of life. By staring at star glint—the bright reflection of light off an ocean—astronomers should be able to map planetary continents and discover many of their alien Everests and Grand Canyons.

No longer a sea of nearly identical stars, the night sky will be populated by *places*: planets with names and characteristics we will come to know almost as intimately as those of Jupiter or Mars. This era of discovery begins now, with NASA's latest planet hunter, the Transiting Exoplanet Survey Satellite. Launched in April, the TESS mission marks a new chapter in the way scientists study exoplanets. We will no longer be astounded—as we have been over the last decade—by the sheer number of planets in the cosmos, but by the diversity of their structures and constituents.

"When I was a kid and my dad took me outside to teach me the constellations, there were certain things that he pointed out to me that you couldn't necessarily see with your naked eye," says Padi Boyd, an astronomer at NASA's Goddard Space Flight Center in Maryland. Her father would point out the three stars of Orion's Belt and tell her something spectacular could be found near them:

NASA/GSFC



Kepler revealed a sky like the one in this artist's impression—bursting with exoplanets. TESS (opposite) will reveal the natures of these alien places.

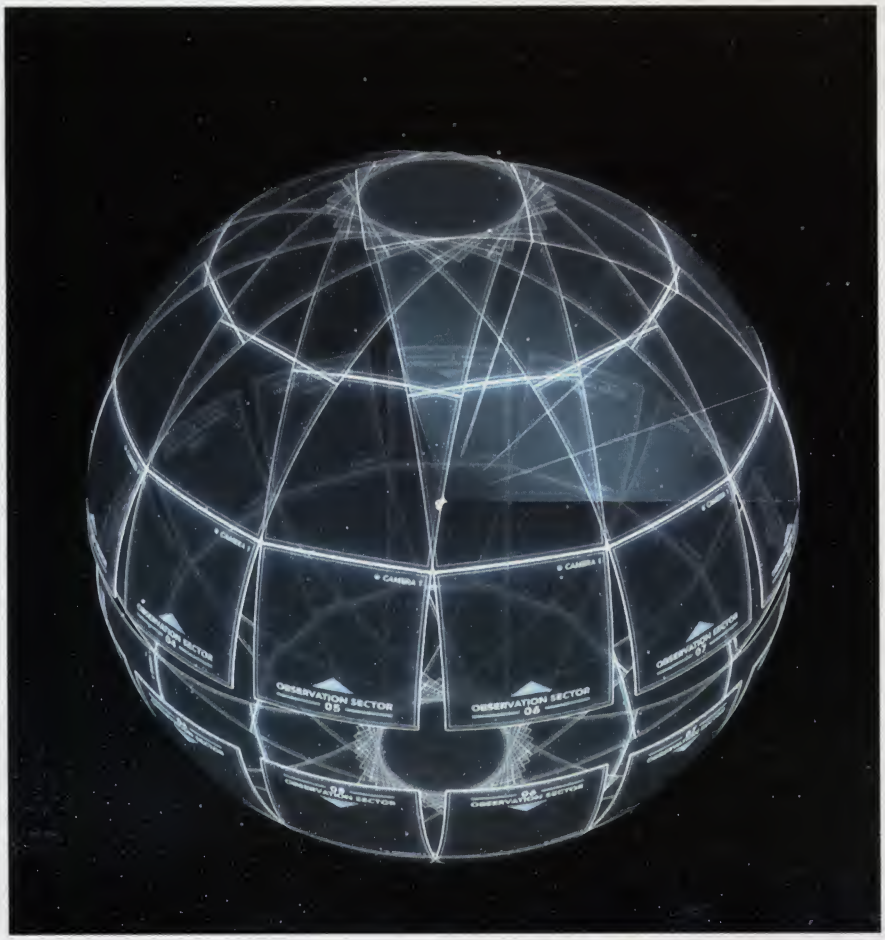
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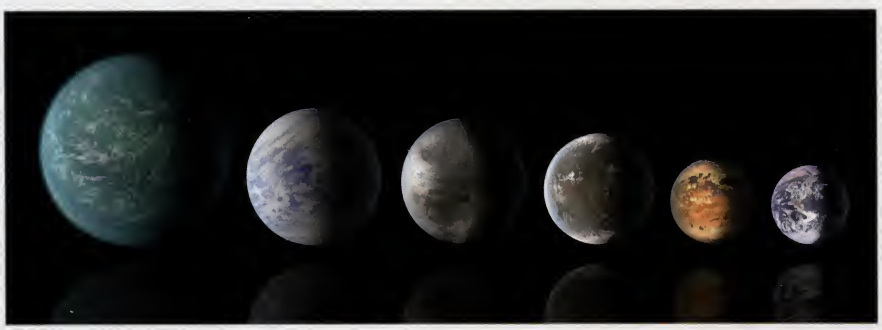
the purple cotton-candy puff of the Orion Nebula, where new stars were being born. Boyd couldn't see it, not without a telescope, but astronomers knew a lot about it.

"But we were never talking about planets around other stars," Boyd says. "Thanks to TESS, you will be able to go outside in a couple years with your kids and not just talk about the nebulas you can't see in those constellations, but the planets you can't see."

The idea that there might be another Earth-like world out there became real in October 1995. Astronomers Michel Mayor and Didier Queloz announced they had found a planet around the star 51 Pegasi, the first discovery of an exoplanet around a star like our sun. It would take another 15 years for astronomers to fully realize how planet-packed this corner of the galaxy is. In February 2011, scientists working with NASA's Kepler Space Telescope announced the discovery of more than 1,300 possible planets. The discovery of so many alien worlds, and of so many types, upended astronomy.

"Kepler taught us that planets are everywhere. That is the best answer we could have possibly hoped for," Boyd says. "On average, you can assume that every star out there has a planet around it." There





A sphere (top) shows how TESS will parcel out the sky, viewing each segment for 27 days. Will we find Earth 2.0? The planets above are real (though depicted by an artist), discovered by Kepler in habitable-zone orbits. TESS could find a million more.

are currently more than 3,700 confirmed exoplanets, nearly three-quarters of which Kepler discovered. (Kepler operated long enough to have a successful follow-on mission called K2, but the spacecraft is nearly out of fuel.)

Kepler was the first mission dedicated to finding these worlds, but it was a census-taker, built to determine how many and what kind. Without any knowledge of what the cosmos held in store, Kepler engineers designed it to look at one small patch of sky, in search of something familiar: objects comparable to Earth, orbiting solar-type stars. Even with this limited targeting, it managed to find a litany of planets, from scorched rock balls to hot, Jupiter-like gas giants in unimaginably small orbits to super-Earths nearly the size of Neptune. TESS principal investigator George Ricker, an astronomer at MIT's Kavli Institute, says that most of the planets Kepler found are distant—too far away for even the most powerful telescopes to distinguish in meaningful detail.

The TESS mission addresses this problem by looking at stars that are much closer to Earth. While Kepler looked at one small patch and peered deeply, TESS will take a shallower look in almost every direction. It will use four cameras to build a map of 85 percent of the sky, nearly 350 times bigger than the field Kepler studied. In this way, it will serve as an in-depth demographer to Kepler's first census. "I think of [Kepler] like a survey, like taking a poll of the planets that are out there and using that to extrapolate something about the larger population," says Shawn Domagal-Goldman, an astrobiologist at Goddard. "Much like we have public opinion polls, eventually we want to do something more like a focus group, and get to know these planets a little better."

Like Kepler, TESS will find exoplanets by looking for changes in a star's brightness. Its light curve will show the dimming that indicates a planet passing in front of it. These transits help determine a planet's size, but TESS doesn't carry a spectroscope, which is necessary to calculate a planet's mass. So an integral part of its mission is to distribute its data to astronomers using the coming generation of telescopes, which will be able to inspect the planets in detail. "TESS is going to be this scouting mission," says Natalia Guerrero, who is one of the leaders of the team that makes first identifications of the objects observed. "We really want to find stars that are easy to follow up from the ground and [from] other space telescopes."

Kepler sent back data in a slow drip, but TESS will be a firehose. Part of the reason for the difference in rate is a difference in orbit. Kepler trailed behind Earth in a matching solar orbit, continuously slipping farther behind us; for this reason, Kepler's data-return rates slowly diminished to the point where astronomers could download only about one megabit per second. Although Kepler's sensors could see many more stars, the observatory was able to transmit data for only 150,000 stars over its mission life.

TESS, by contrast, is traveling in a complex, highly elliptical orbit that sends it swinging out to almost the distance of the moon and back every two weeks. This

TOP: NASA GODDARD MEDIA STUDIOS; BOTTOM: NASA AMES/JPL-CALTECH

orbit maximizes the amount of sky TESS can see without glare from the moon or Earth, and uses the moon's gravity to stabilize the spacecraft and lower the fuel requirement, an economy that could prolong the mission's life. As TESS swings back around Earth, it dumps out its previous several weeks of data at 100 megabits per second. Over the course of its planned two-year mission, the spacecraft should be able to send home data on more than 20 million stars. The mission officially began observations in June, and the first data will be released this January.

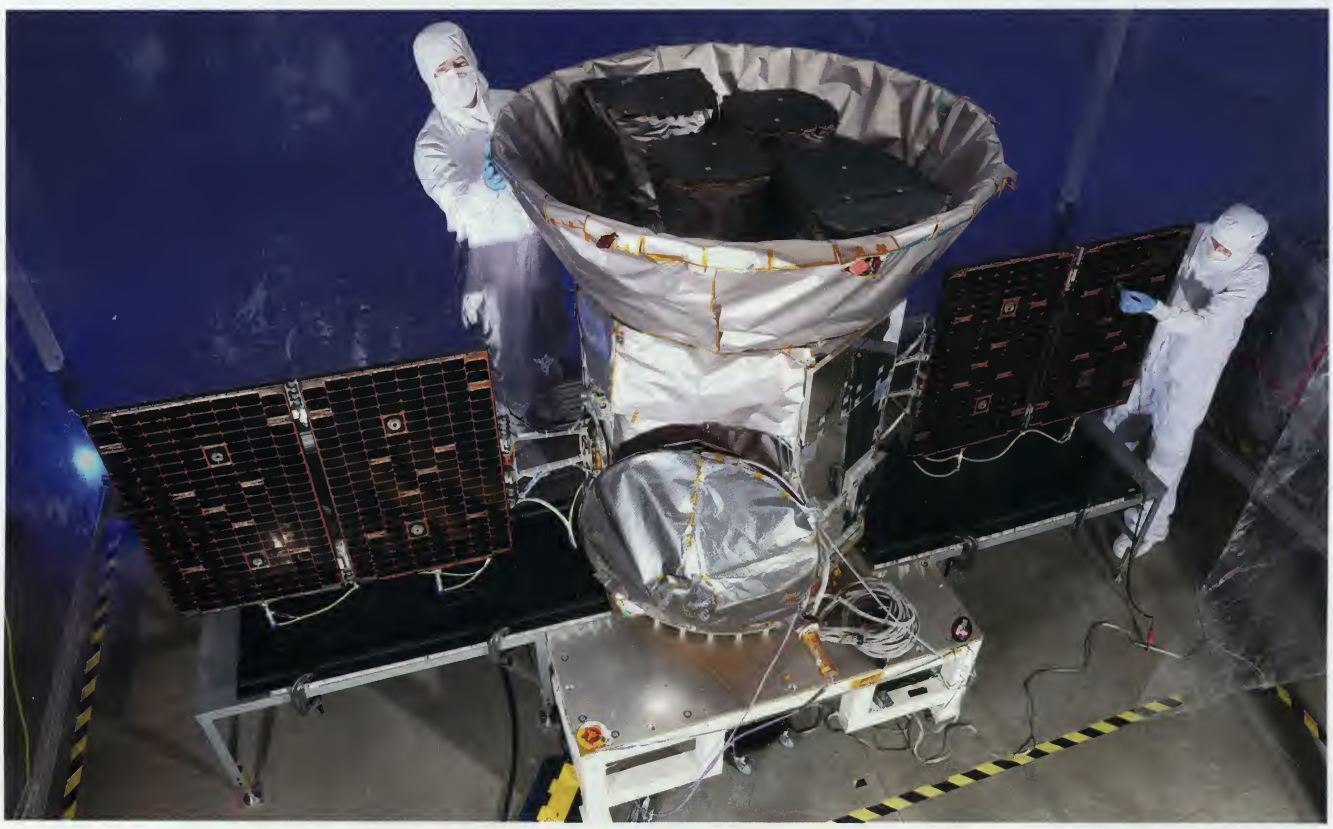
The stars TESS is targeting are, mostly by virtue of being closer to Earth, 30 to 100 times brighter than those Kepler studied. They include the few stars whose light manages to make it through the glare of the world's major cities. "TESS can look at every single one of those and see whether there are planets," Ricker says. "If even only a few of them, even two or three, turn out to be associated with planets, that's going to be a wonder." Everyone on Earth will be able to look up and point at another world.

TESS will capture the sky in strip-like sections about the size of the Orion constellation (see illustration, p. 36). TESS will take enormous, full-frame images every 30 minutes, while also monitoring thousands more stars in the background every two minutes, creating multiple layers that are later compiled by a supercomputer at NASA's Ames Research Center in California. Starting with the southern hemisphere, TESS will work through each section in 27 days, then shift to the next, covering the entire sky in two years. The mission could be extended beyond its initial run, in which case TESS will start over and observe each hemisphere again.

Mission designers expect the spacecraft to find many objects besides exoplanets. Since its cameras will be measuring relatively rapid brightness changes in the same direction, it will end up creating a catalog of fast-changing objects throughout the whole sky. Ricker, who started his career studying phenomena like gamma-ray bursts, says the mission's contribution to transient astronomy will be enormous. TESS will see all types of stellar outbursts: the relatively gentle nova of one star gobbling up its partner star, the "standard candle" Type 1a supernovas used to study the universe's expansion, and the newly discovered phenomenon known as a kilonova—the eruption that occurs when a high-energy binary system, like two black holes or neutron stars, collapses. Ricker says the TESS team is preparing by analyzing data from the now-famous August 17, 2017 neutron star merger, the second confirmed observation of gravitational waves. The merger was



It's a giant space camera. TESS carries four (below) and no other instruments. Mission lead George Ricker (right) holds a piece of the sensitive CCD.



TOP: NASA/BILL INGALLS; BOTTOM: NASA

the first gravitational wave-producing phenomenon to be followed up by observations in every wavelength of light. The team believes TESS should be able to record—and identify—similar events.

This is the kind of mission in which one person's trash is another's treasure, says Guerrero. All of TESS's observations will be available to anyone who wants to take a peek. This is a departure from prior missions—most notably, once again, Kepler, which withheld some intriguing data for several months so NASA scientists and mission partners could analyze it first. This proprietary period sparked controversy, as other exoplaneteers were also waiting to get their hands on the Kepler information. TESS will have no such lock-down, Guerrero and Ricker say.

"There's a commissioning period" as the Ames supercomputer calibrates the measurements, removes glitches, and layers the data into light curves, "but once data goes into the archive, it's available to everybody," Ricker says. "We used to say, when we were striving to get TESS approved and flown, that it was to serve as the people's telescope. Whether you're an amateur or a professional astronomer, the TESS data will be there for you" in the Space Telescope Science Institute's archive, the database originally created for Hubble.



A few weeks after its April launch, TESS took its first swing around the moon and opened its cameras. This two-second exposure (below) is a tiny glimpse at the data Natalia Guerrero (left) and her team will use to identify exoplanets.

KEPLER FOUND SO MANY PLANETS, and in such short order, that astronomers watched exoplanet discoveries evolve from a headline-grabbing phenomenon to a snooze fest. But TESS will carry the field into something wholly new that Stephen Rinehart, TESS's pre-launch project scientist, calls comparative planetology.

Goddard astrobiologist Domagal-Goldman says exoplanet researchers typically fall into one of two broad categories: astronomers who are making the initial observations to discover and categorize the planets by size and orbit, and scientists who use spectroscopy to study the planets' atmospheres in order to characterize what kind of worlds they are. An exoplanet broadly categorized by the first group as "Earth-like" could also include places like Venus and Mars, but it's the second group that could distinguish them enough to determine which one might harbor the kind of life with which we're familiar. Sussing out the details of these faraway planets could tell us...well, we just don't know yet. It could tell us any number of things about the potential for life in the universe, but at the moment, the spectroscopists don't have a whole lot to look at.



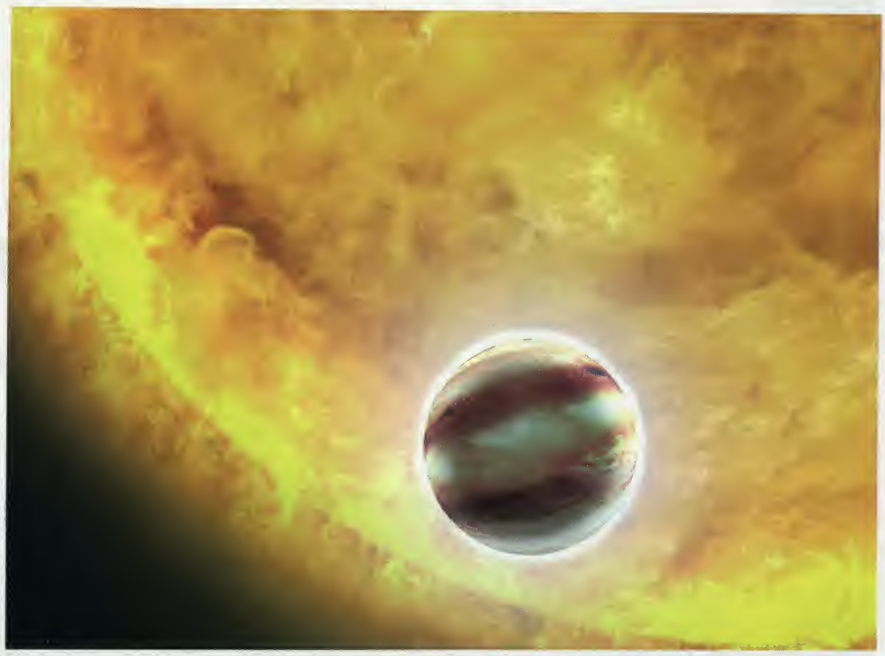
TOP: NASA/BEN SMEGELSKY; BOTTOM: NASA/MIT/TESS

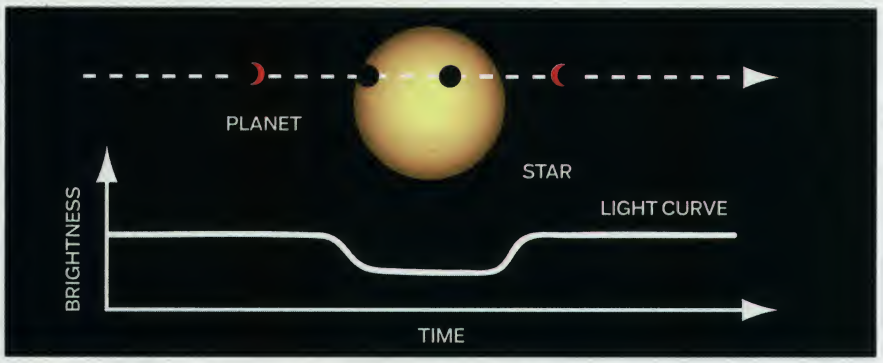
"What's fun about TESS is that I'm already seeing in my colleagues how those communities are starting to talk to each other a lot more," Domagal-Goldman says. "Now these spectroscopists are really interested in the discoveries in a way they haven't been before.... And for the discovery people, these planets are their babies. When they find them and write a paper about them, they love them and they want to know more about them. The best way to do that is to partner up with someone who is an expert in spectroscopy, who might" get time on a powerful telescope to study it in detail.

Rinehart says this change in the community is also generational. Younger astronomers are more willing to share data they've collected, and make their programming code for analysis and models open source for colleagues. "The old model for astronomy was 'That's my data, keep your hands off my data,' " he says. "Today people seem to be in general way more collaborative, way more open to sharing ideas, and saying 'Hey, we can all work together on this and get more cool results out.' "

What discoveries come from TESS will depend not just on a collaborative community but on which observatories astronomers will have access to in the near future. TESS will discover new things on its own, but its real value will be in enabling others to stand on its shoulders. The James Webb Space Telescope, now scheduled to launch no sooner than May 2020, and giant ground telescopes, like the Keck Observatory in Hawaii and those under construction in Chile's Atacama Desert, will be essential for characterizing these new worlds. Those telescopes, not TESS, will be able to see the first signal of alien life on a distant "rainbow dot," as Domagal-Goldman puts it.

No one knows what the new planets will look like, but thanks to Kepler, we do know there will be some weird ones. "There are these lava planets, water worlds, planets that rain rubies; there are mini-Neptunes, which we don't have in our solar system," Guerrero says. "Those are really interesting planets we've already found. With TESS, we are just trying to answer this big question: Is our solar system common or is it unique?"





TESS records the changing brightness of stars to create light curves like the one above. More powerful telescopes get the details: Astronomers have used Hubble to look for water vapor on this Jupiter-like exoplanet (top, artist's conception).

Domagal-Goldman created a thought experiment to imagine how TESS could enable astronomers to find alien life. First, TESS would have to find a rocky world in the habitable zone of a relatively unremarkable star—close enough to the star's heat for liquid water to exist, but far enough away to be out of the reach of stellar flares. If the star was close to our solar system—say five light-years away—astronomers using telescopes soon to be built could take its picture.

"You could take snapshots of that pale blue dot, a whole-disk image, and you could see changes as the planet rotates under the telescope," Domagal-Goldman says. "You could start to map out continents and clouds. You might even be able to see something like a massive rainforest. You might be able to see stuff change, as you do [with] the seasons on Earth. If we saw oxygen, well, oxygen by itself is not enough. Oxygen and methane is better. Oceans, which we might detect through a glint, would be even better. Then, if we have a hint of green...that's the point where I am starting to say: How else do you explain the full set of data without life?"

Ultimately, the proof that life exists on an exoplanet may come only when humanity figures out a way to send emissaries to the stars, a mission that will likely happen so far beyond our lifetimes it seems like fantasy. But if that fantasy mission ever comes to pass, the course it plots will be rooted in the work TESS is doing right now.

TOP: NASA, ESA, AND G. BACON (STSCI); BOTTOM: NASA AMES

American Spacelines

FIRST IN A SERIES

Astronauts,

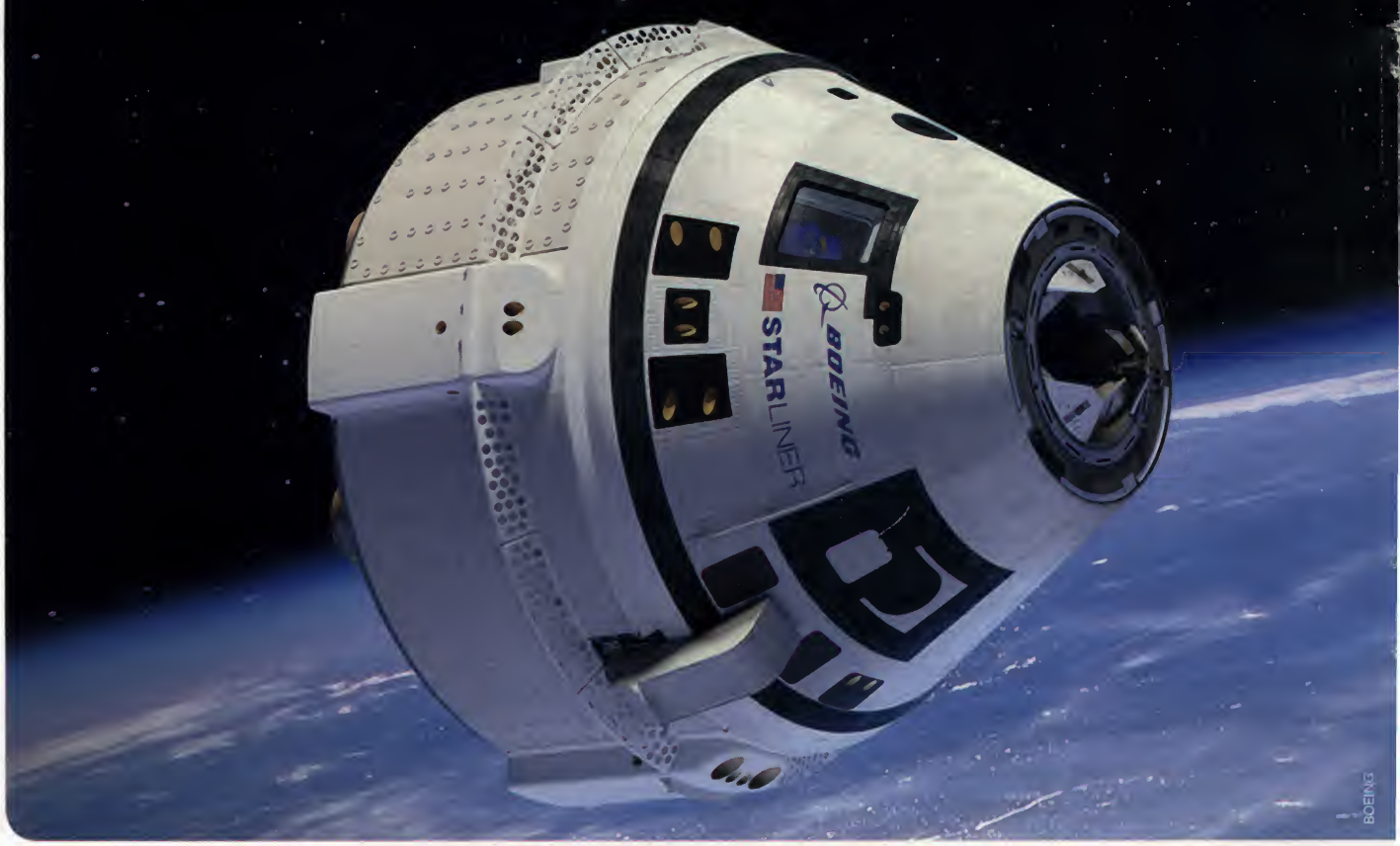
NEW TAXI SERVICE TO THE INTERNATIONAL SPACE STATION.

FOR MORE THAN seven years, U.S. astronauts have blasted into orbit from a Russian launch pad in Central Asia. Now Cape Canaveral is about to reclaim its position as center stage of the American space program.

A pair of privately owned spaceships, Boeing's Starliner and SpaceX's Crew Dragon, are set to make their debut within the next few months, ending NASA's post-space-shuttle reliance on the Soyuz to ferry astronauts to and from the International Space Station. For each new vehicle, a single, uncrewed test flight to the station will be followed by a second test flight with at least two astronauts on board. Each company has contracted for up to six additional taxi flights, during which the Starliner or Crew Dragon will dock with the station, remain attached for six months as a lifeboat for the crew, then return the astronauts to Earth.

Although the ships seem like a nod to the past—Apollo-style "capsules" instead of the spaceplanes astronauts rode to orbit for 30 years—NASA hopes this will be a smarter approach to space transportation. From now on, the agency will be buying tickets for its astronauts, rather than inventing, owning, and operating the spacecraft itself.

Which is not to say the vehicles were privately funded. NASA paid nearly all the development costs and ultimately will shell out more than $8 billion to Boeing and SpaceX to



BY TONY REICHHARDT

Your Ride's Here!

build and certify the new spacecraft, conduct two test flights, and provide up to six taxi flights each by 2024. That's way more than the $3.4 billion NASA paid for 64 Soyuz seats between 2006 and 2018. But Russian prices have risen sharply in recent years, and the agency expects seats on the new SpaceX and Boeing taxis will end up being cheaper.

What would a NASA shuttle veteran find different about these new spaceships?

Autonomy, for one. Both the Starliner and Crew Dragon will travel to the station and dock automatically, with no astronaut input. (The crew can take manual control if something goes wrong.) This greatly reduces the complexity and weight of onboard controls. Autonomy also simplifies training: Astronauts bound for the space station can focus more on the jobs they'll be doing in orbit.

The new vehicles should also be safer, with escape systems that—unlike the space shuttle—can propel the crew to safety in the event of a launch pad explosion. Designers are working to a challenging safety standard: a 1-in-270 chance of a fatal accident, as compared to the 1-in-90 chance calculated for the space shuttle by the time it retired in 2011.

As the Starliner and Crew Dragon begin operations over the next year, we'll explain more about how the vehicles work and what the new space taxi service means for NASA's astronauts.



SPACEX



Boeing Starliner

Up to $4.9 billion

Apollo, Space Shuttle Boeing and its corporate predecessors have long experience manufacturing space vehicles. North American Rockwell built the Apollo Command Module.

Up to 7 NASA required that each vehicle be able to transport four people to and from the station. A fifth seat is available on both vehicles. Each company advertises a seating capacity of seven.

Diameter: 15 ft. Height: 16.6 ft.
Dimensions include service (propulsion) module.

Aerojet/Rocketdyne Engines for abort and for maneuvering the Starliner in orbit are located in the disposable service module.

Yes Crew capsule can be reflown up to 10 times. Service module will be discarded after each flight.

Atlas V 422 /Centaur Will be compatible with other rockets in future.

Cape Canaveral Launch Complex 41

Western U.S. Starliner will parachute to dry land, like Soyuz, and use airbags to cushion the impact. Landing sites at White Sands, NM; Dugway Proving Ground, UT; Edwards AFB, CA; Willcox Playa, AZ.



SpaceX Crew Dragon

Price	**Up to $3.2 billion** Numbers for both companies include total NASA contract awards for developing, building, and certifying vehicles, two test flights, and up to six ferry flights to the ISS through 2024.
Heritage	**Dragon Cargo Vehicle** SpaceX has been launching supplies to the space station since 2012. Crew Dragon is based on the Dragon cargo craft.
Seating Capacity	**Up to 7**
Head / Leg Room	**Diameter: 12.1 ft. Height: 23.6 ft.** Dimensions include Dragon's cargo "trunk."
Engines	**SpaceX Draco / Superdraco** Engines are onboard. Superdraco engines are used for abort only.
Reusable?	**Yes** Dragons are reusable, although test flights will fly new vehicles. Cargo trunk is discarded after each flight.
Launch Vehicle	**Falcon 9 Block 5**
Launch site	**Cape Canaveral** LC 39A (same pad used for Apollo 11 and the space shuttle)
Landing site	**Atlantic Ocean/Gulf of Mexico** Ocean splashdowns, similar to how SpaceX cargo craft return from the space station.

OPPOSITE, TOP: BOEING; ABOVE: SPACEX

WHERE'S *the* PROP?

FIRST FLIGHTS IN THE FIRST JETS. BY DAVID SEARS

PILOTS WHO FOUGHT in the last years of World War II were flying airplanes refined by years of combat experience and engineering, the most advanced piston-engine aircraft ever built. Post-war, they were subjected to something entirely new: jet-powered fighters. The basics of flying were the same, but the propulsion was revolutionary. Few two-seat trainers existed. "Besides, since you're all experienced fighter pilots," one squadron leader told his cadre of jet aviation novices, "you don't need any dual instruction before flying jets." But the transition from propeller-driven airplanes was daunting—23 military jets crashed between 1945 and 1950, killing 36 (including victims on the ground). Among the dead was the highest-scoring U.S. ace of the war, Richard Bong, killed during a Lockheed P-80 Shooting Star test flight. The following accounts of early jet experiences come from veteran aviators who entered the Jet Age the hard way.



An Me 262 replica flies a Mustang near the Military Aviation Museum in Virginia Beach. For pilots of propeller-driven airplanes, used to small differences between top speeds, jets were a shock: Me 262s were 120 mph faster than P-51s.

LYLE JANSMA/AEROCAPTURE IMAGES

Roy W. Brown Jr.

First Lieutenant, U.S. Army Air Forces
1945: P-47 Thunderbolt to Me 262 Swallow

I flew 84 P-47 combat missions. I engaged German fighters just once, late in the war not far from the Rhine [river]. My wingman saw Fw 190s flying in the opposite direction. I got on the tail of one. The P-47 was not as maneuverable as the 190, but the 190 had a flaw. In a real sharp turn to the left, it would stall. I found out I could turn inside him. I got strikes and he eventually bailed out.

On V-E Day [Victory in Europe, May 8, 1945], I was told the Air Force wanted to talk to a couple of pilots from our group. In my case, they came to me and asked what I knew about jet engines. I told them I didn't know much, but I was a chemical engineer. On June 3, I was flown to Lechfeld where they were working on Me 262s. There were quite a few German mechanics and two German test pilots; they were pro-American and spoke very good English. Not only had I never flown a jet, I'd never flown a twin-engine aircraft or one with tricycle landing gear. All of it was new to me.

The Me 262 was nice-looking, more streamlined than a P-47 and not as noisy. The controls—throttle, stick, and the rudder pedals—were about the same as a P-47. Starting up was more complicated: You had to get the engine to 1,000 rpm or so before you could start feeding fuel.

On June 10, we flew nine planes to Melun, near Paris. We had gotten used to the controls and instru-



ments, but my very first flight wasn't until June 8, in a two-seat, dual-control version. Karl Baur, one of the German test pilots, sat in the back seat and took each of us up. Before we took off Baur said: "When you come in for a landing keep your speed. If you're throttled back then need power, you can push the throttle forward, but you won't get power until the engine rpms come back up." That's really all he said. So I took off, flew the traffic pattern, and landed. Eight minutes. I don't think Baur touched the controls.

On the 10th, they lined up all nine planes. The weather was good, sunny and clear. Mine was number six. We took off one at a time at 20-minute intervals. That way, if one plane had a problem landing at Melun, they'd have time to clear it before the next plane came. The distance to Melun was 375 miles. Near ground level, the Me 262's range was only about 300 miles, but I figured if I got up to about 10,000 feet and flew straight to Melun I'd have plenty of fuel. We had no radio but we had maps, and I'd been flying that area for four or five months, so I had no problem until I'd flown about halfway, [beyond familiar territory]. I didn't see any landmarks but before I really worried about it, I saw the field ahead and to the left. I was the sixth to take off but the first to land. All the others made it safely. In July, we flew the aircraft to Cherbourg so they could be loaded onto an aircraft carrier for transport to the States.

I don't remember any apprehension about flying the Me 262. It was just another flight we had to make. We just learned what we needed to. Just another assignment.



F9F Panthers were only four months in service when photographed aboard the USS *Boxer* in September 1949. They were already outclassed by MiG-15s when the Korean War began the following June.

US NAVY

Lester R. "Bud" Smith

Ensign, U.S. Navy

1950: F4U Corsair / F6F Hellcat to F9F Panther

I was slated to go to Korea in the F4U. When I reported to [Naval Air Station] San Diego in September 1950, I was still a flying midshipman. They allowed me to check out in F6Fs, so I was alternating flying F6Fs and F4Us. We younger pilots used to do "combat." I never did lose a "battle." The F4U can't stay with the F6F in a turning circle so when I flew in the F4U, I made the battle go vertical. An F6F just can't accelerate with an F4U.

When the *Essex* air group came back from Korea we were supposed to fill in for people being transferred out. I was told I was going to be in VF-53, an F4U squadron. But when they cut the orders, I was ordered to VF-52, a jet squadron. I thought there was a typo, but I wasn't going to tell anybody. At that time, they were flying F9F-3s.

Lockheed will tell you that nine out of 10 jet pilots are trained in Lockheed jets—the T-33. That's true, but I'm one of those one out of 10; my first [jet] flight was in an F9F-3 on the 18th of December, 1950, just a couple weeks after I joined the squadron. There were four of us with an experienced flight leader. They told us it would be slow getting in the air. Don't pull the stick back until you got to 105 mph. I had gone 4,000 feet down the runway, about halfway, and I hadn't even cracked 40 mph. I figured the airplane was going to go off the runway into the bay, and they were going to fish me out. Suddenly, the airspeed indicator started to move visibly: 105, 110, 125. The airplane started to lift off at about 140 and I was airborne.

The flight leader put us in echelon formation at 20,000 feet. He would peel off and you would follow him after 20-second intervals. Then he would turn 180 [degrees] and you would rejoin him—or try to. In an F4U, you can have 40 knots on the leader, go sliding in there fast, pull the power back, and that big prop becomes a brake, slows you down on the spot. The first time I did that in the Panther, though, I

came sliding in there smartly, pulled the power back to idle—and I went by him like a rocket. You have to think way ahead of the jet.

Landing was good because of the visibility from a tricycle landing gear airplane: You could see down the end of the nose. But that first field landing—when I put it close to the runway and held the nose off to slow down, the doggone airplane didn't slow. It kept rolling like it's going to roll forever. I'd say I used three-quarters of the runway that first time.

The bad thing about the F9F-3 was its Allison engine. It was not very reliable. I had 136 carrier combat missions in Korea, all in F9F-2s [a later and better version, despite the number] and, boy, I bless myself.

Clarence E. "Bud" Anderson

Major, U.S. Air Force

1950: P-39 Airacobra / P-51 Mustang / P-82 Twin Mustang to F-94 Starfire

I thought the P-39 was great until I flew the P-51. We didn't have P-51 pilot manuals, but we were so happy to get them we didn't care. Still is my favorite aircraft: looked good, flew good, made a great sound. Long range but still quite maneuverable. I went into combat in February '44. I flew 116 missions and got 16 kills: eight Bf 109s, eight Fw 190s, and one-fourth of a Heinkel 111.

I ended up being at [Dayton, Ohio's] Wright Field in 1947 or 1948, but I had to go to Alaska first. Took a P-82 Twin Mustang up there and tested it in the cold weather. Beautiful country but a lousy airplane. In April 1950, we got our first F-94B—a stripped-down version with no controls in the back. Before my first flight I just got in and familiarized myself. You have the same basic flight controls. Someone stood on the wing, leaning over my shoulder, explaining the controls. The pilot who was to take it up next leaned over my other shoulder listening in.

Meanwhile, my boss Dick Johnson—a big practical joker—snuck in the back where the radar operator would fly. A huge panel of data-gathering instruments separated the two compartments so I couldn't see him. After the briefing I fired it up, lowered the canopy, taxied out, and took off. Unlike in the Mustang, for takeoff you didn't have to hold a bunch of rudder to offset the torque. Jets went straight down the middle, though the earlier ones took a little bit longer to roll. Tricycle gear also made it easier. You were looking down the runway right away. The engines were the big thing. The early engines were not as reliable as the good old Merlins. But as far as flying, you didn't have to worry about big trim changes. Did I notice the speed difference? Oh, God, yes!

My house was right off the end of the runway, so whenever I took off, I always banked off over there to inspect my investment.

Suddenly: "I'm on your ass! You've got 10 seconds to get me off!"

I slammed my stick sideways. React first, figure it out later. I though it was some jerk jumping me on takeoff, sucking me into a dogfight. I'm trying to shake him, deceive him, you know, even though it's a test flight. Pretty soon, Dick couldn't help it—he laughed. I'd been had, but I think Dick had second thoughts. When we landed, he crawled out sweaty, his oxygen mask askew.



USAF

The F-94 Starfire was among the first U.S. Air Force all-weather jet fighters and was Lockheed's interim step between the P-80 and F-104 Starfighter. Technology changed so rapidly in the post-World War II period that only 10 years separated the Starfire's first flight from its retirement.

Kenneth O. Chilstrom

Captain, U.S. Army Air Forces
1945: P-40 Warhawk / A-36 Apache to P-59 Airacomet

I flew the P-40N model. We put 75 new aircraft on board the USS *Ranger* at Norfolk. About 100 miles from Casablanca, they launched us. I was number 35, right in the middle of the pack. The propeller torque got each one, and they drifted off to the left. Down near the water, they got additional ground effect lift, so we all made it. I transitioned to the A-36, an early P-51 model with dive brakes. It was easier to handle than the P-40 but had a single-stage blower so we didn't fly much above 12,000 feet. Quite lethal against trains, trucks, anything that moved. I had 80 missions over Sicily and Italy and came home in November 1943.

My next assignment was Wright Field—first in maintenance, but after six months, I transferred to test operations. The first jet I flew was the Bell P-59. We were given briefings by the contractors. Most airplanes follow the same pattern as far as the cockpit and controls. A jet is just different propulsion.

I ended up being the project guy on the -59 and in February 1945, had the first major jet accident in a U.S. military airplane. We had two P-59s at Wright Field and one was supposed to go to [the National Advisory Committee for Aeronautics] at Langley Field [in Virginia]. The weather was marginal the morning I was going to deliver the airplane, [but] the weather changed. So I took off in the P-59 and climbed to 20,000 [feet], intending to refuel at Roanoke before going on to Langley. But the weather was unsatisfactory for a VFR landing at Roanoke, and I didn't have the electronics for an instrument landing.



Not all jets were superior to props. Despite propulsion from two General Electric J31 turbojets, the P-59 was slower than contemporary piston-engine airplanes, and never saw combat; some were kept to teach U.S. pilots how to fly jets. In contrast, pilots flying the F-86 (opposite), considered it the best fighter airplane of its era.

USAF

I turned towards Greensboro [North Carolina]—my alternate—but halfway there, one engine stopped for lack of fuel. Near Reidsville, I saw a little 3,000-foot airstrip. I landed, got refueled, and made plans to take off in the morning for Langley.

On takeoff, I got about halfway down the runway, and I lost thrust. I didn't have enough runway to put it back on the ground, so I went into the trees. The airplane was completely torn apart. The nose, the tail, all the right wing, and half the left wing came off. What saved me was the fact that the two engines gave structure to the cockpit. When I stepped out, the airplane was on fire. Fortunately, kerosene doesn't burn like gasoline. I was wearing a Notre Dame-style football helmet. I had a bump on my forehead from hitting the stick, but that was all. I called Wright Field and they sent a converted P-38 two-seater to pick me up. Next day I was back at Wright Field.

Donald Q. Griffith

Captain, Ohio Air National Guard
1951: P-40 Warhawk / F-51 Mustang to F-84 Thunderjet / F-86 Sabre

I got my wings in '44. I transitioned into the P-40 and then the P-51. The P-40 was big, and the P-51 was much smaller and faster. We got combat-ready in a P-51, and we were ready to ship to Europe but the war ended. I went to college, flew P-51s on the weekend, and had a really good time. I graduated, started work, got married, had a boy, and then found myself called back to active duty in 1951.

We were changing to jets by now—the F-84C Thunderjet—but we had no two-place airplanes. They just put us in the cockpit. We started the engine, they said good luck, and away we went. The Mustang and Thunderjet have different gauges, switches, and procedures, but [familiarization] is all done on the ramp while you're studying the cockpit. Once you get in the air, flying them is not that much different. The only real transition was takeoff and landing: using rudder for the Mustang, needing more runway for the Thunderjet. The F-84 probably had less vibration than a P-51, but it was not a quiet aircraft. It was underpowered and relatively slow. Also, a lot heavier; it's built to carry bombs. The -51 was built for shooting guns.

When we got orders to go to Korea, three of us got assigned to the F-86s while the rest of the guys went F-84. Transitioning to the F-86—that was no problem. I got to Korea in June 1951, 4th Fighter Group, 335th Fighter Squadron. I flew 68 combat missions. Shooting was easier because you didn't have to put in rudder all the time to fight the prop torque. The F-86 was the best airplane in the world.

JOHN DIBBS/THE PLANE PICTURE COMPANY



A P-80 (soon redesignated F-80) on the tarmac in Cleveland, Ohio. Though not available to George Loving, two-seat versions like the T-33 were common in U.S. service from the 1950s until the '70s.

George G. Loving Jr.

Captain, U.S. Air Force
1951: Spitfire / P-51 Mustang / P-47 Thunderbolt to F-80 Shooting Star

I joined the 31st Fighter Group in Italy in October 1943, and flew 101 combat missions in Spitfires Mark V and Mark IX—probably the best fighter aircraft in the world but didn't have enough range. I had been in the outfit five months when we got P-51 Mustangs. The P-51 was the one that had the range. It ended up being the best fighter airplane at the end of the war. I flew 50 more missions in a P-51 and shot down five enemy aircraft. My post-combat flying assignment was as a P-47 instructor.

I was at Langley when North Korea invaded South Korea. Far East Air Force requested Mustang pilots, so I volunteered. The available airfields in Korea had short, unimproved runways, so there was an urgent need for Mustangs. I flew a half-dozen close air support missions from Taegu, Korea before I got sidetracked into flight operations.

Then my group commander asked me if I wanted to get into jets. I said yes, so he assigned me to the 49th Fighter Group, 9th Squadron. The squadron operations officer handed me a copy of the F-80 operating instructions. "You know the drill," he said. I studied the instructions for a day and passed a 50-question written examination. Then I spent time in the cockpit and took a blindfold test. Bud Evans, an old hand in the squadron, called out the names of controls, gauges, switches, and levers; I pointed to the location or touched it.

They didn't have a two-seater to check out with. I flew an F-80C with Bud tagging along. I made some turns and stalls, a couple of chandelles and barrel rolls, a high-speed dive, and a high-G recovery. I was an experienced fighter pilot and I knew the ropes. The F-80 was a wonderful airplane: very stable, forgiving, no bad habits, very versatile. It was very easy to fly. So I got 10 hours, and then I started flying combat. For the rest of the war, I flew the F-80 [on] 113 missions.

My first combat mission in the F-80 wasn't very exciting. We rocketed a building which supposedly contained a lot of enemy troops. Later I did all sorts of things: dive-bombed airfields, did dawn searches for locomotives, put bombs in tunnel entrances, did rescue missions—everything you could think of. My most memorable F-80 flight I think was the May 1951 raid on Sinuiju airfield right across the Yalu River from the Antung MiG base. I led 42 F-80s in an attack on Sinuiju's anti-aircraft emplacements. Several hundred airplanes were involved. We wiped it out.

NASA



Edward B. "Buzz" Purcell Jr.
Lieutenant, U.S. Navy
1953: F4U Corsair to F2H Banshee

I got my wings in December of 1945, but they let us out of the Navy so I returned to college. I was called up for Korea in '52, went to Moffett Field, and joined VF-152, an F4U squadron. It was really a thrill to fly that plane. I flew 25 combat missions in an F4U.

When we got back from Korea, our squadron received the F2H-3 Banshee. The squadron commander told us we were experienced fighter pilots; we didn't need any more special training. We got the Banshee handbook and studied that for a couple weeks. We had to know all the emergency procedures and pass a blindfold cockpit checkout. Within a month, we started flying. On my first hop, I did everything according to the way they told us: Try a few stalls but be sure you're at about 20,000 feet. On your first landing, don't come to a full stop. Take off again, come around, shoot three or four landings. The Banshee did not accelerate like the propeller plane, but it certainly went much faster and it was much quieter. I was humming along, not sure the engine's running. But I'm climbing at 450 knots. Once I came to a stop, I was so happy to be alive I taxied in and went to the O-club and had a drink.

The carrier approach in a Banshee was much easier because your visibility was so good sitting up there in the nose. You don't have anything blocking out the landing signal officer [who, from the deck, corrects pilots' approaches]. The only thing is your speed; you're doing everything much faster.

Trapping in a jet is different. In a jet, once the nose goes down, it's not coming back up. That was a problem for anybody going props to jets. You're sinking, and the only thing you do is maintain your sink rate. We bent a lot of struts.

Not every situation demanded speed, and P-47s (above) remained in service as ground-attackers until 1953. But for air defense, jets like the Banshee (below, in Canadian service) couldn't come quickly enough.



TOP: NASM (74-11710); BOTTOM: ROYAL CANADIAN NAVY

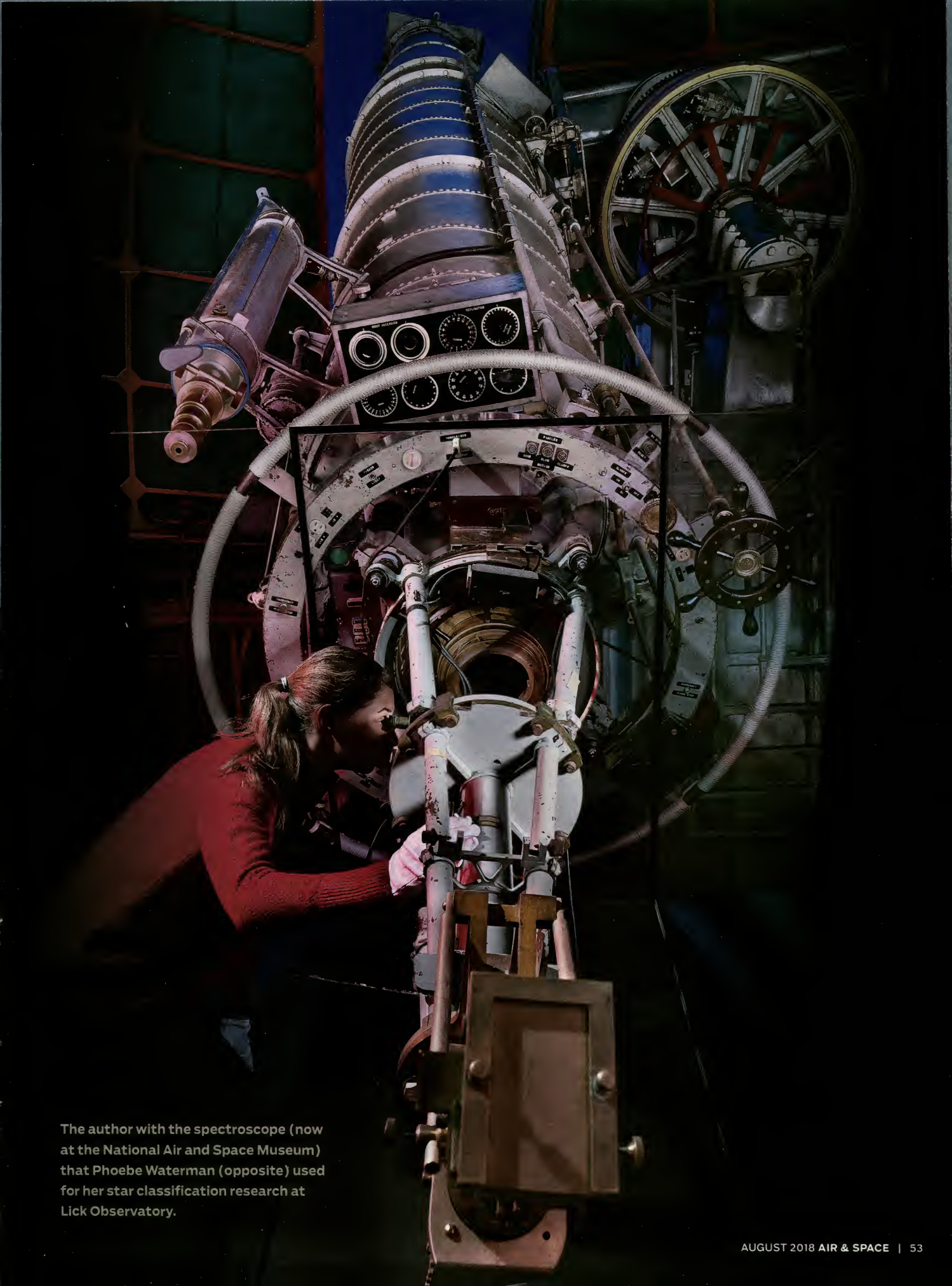
DEVOTED TO THE STARS

A century ago, one woman proved there are many ways to leave a legacy. BY MELISSA JOSKOW

SHE KEPT HER TELESCOPE in a wooden box in the basement. Phoebe Waterman Haas had observed hundreds of stars with it over the years, plotting light curves as their brightness flickered. Her grandson, Thomas Haas, saw the refractor nestled away just once, when he helped her retrieve it one night in 1966. He was 11 years old. "I remember it like it was yesterday," says Tom. "We stayed one evening after dinner. My brothers and sister were there and she brought out this beautiful brass telescope. She put it in the back yard and showed us the stars and the moon." Waterman Haas died the next year, and it was only decades after, when Tom began to research his grandmother's life, that he discovered she knew just a little bit more about stars than the names of the few she taught him that night.



LEFT: NASM (9A12028-083D); OPPOSITE: ERIC LONG/NASM



The author with the spectroscope (now at the National Air and Space Museum) that Phoebe Waterman (opposite) used for her star classification research at Lick Observatory.



Waterman, far left, takes a break with her fellow computers at Mount Wilson Observatory in California during the 1910 Solar Union conference.

Phoebe Waterman Haas was among the first American women to earn a Ph.D. in astronomy. Her doctoral thesis confirmed the usefulness of classifying stars by their spectra, or colors, and upon graduation from the University of California at Berkeley in 1913, she was hoping to embark on a career as an astronomer. But later that year, she was forced to make a choice.

Phoebe Waterman was born in 1882 into a family that valued learning. Her father, John Charles Waterman, was a colonel in the U.S. Army's 7th Cavalry Regiment, fighting in the battles of Little Bighorn (also known as Custer's Last Stand) and at Wounded Knee. He also had a great interest in science, keeping books and field journals about the plants he encountered on his travels, and instilled a love of education and adventure in his children. Phoebe was first home-schooled, and then sent to her father's family in Michigan to complete her high school education. In May 1900, she began the new century visiting her father while he was stationed in Cuba, where she observed a partial solar eclipse. She recorded the experience in her diary: "For about four minutes this a.m. the clouds before the sun broke enough that we could make out the eclipse."

Waterman left Cuba that fall to attend Vassar College. The school, still women-only, had opened its astronomy department in 1865, employing the country's first female professional astronomer, Maria Mitchell, as a professor and director of the observatory. Waterman earned an undergraduate degree in astronomy and stayed on to complete a master's degree in 1906. Caroline Furness, a professor who would become a close friend, encouraged and collaborated with Waterman to get her master's thesis, "The Definitive Orbit of Comet 1880," published in the German astronomical journal *Astronomische Nachrichten* in 1908.

After returning to Vassar for a semester as a substitute teacher, Waterman moved across the country to join the computing staff at the Mount Wilson Solar Observatory, near Pasadena, California. In letters to Furness, Waterman described hiking trips up Mount Wilson, a visit from Andrew Carnegie, and Valentine's Day parties—an active lifestyle that suited her. The work that Waterman was assigned, however, was disappointing. She told Furness that she had hoped the data crunching she was doing—performing mathematical calculations and classifying photographic plates for use by male astronomers—would evolve into an independent project, but that was not happening. Her supervisor, Frederick Seares, "likes to superintend the very details, and gives anyone working under him practically no chance for original work," she wrote. Waterman was getting a small taste of independent inquiry when she worked with astronomer Walter Adams, who often engaged her in discussions on solar rotation and let her pursue some of her own ideas with his data. During those times, she wrote, she "could do it all.... I feel as if I know one piece of the work thoroughly."

Outside of teaching and computing—Waterman had already tried both—there were very few positions for women in astronomy at the turn of the century. "But oh, I do want so much a position as astronomer, part of my work with the instruments and part with the reduction of my plates, as the men here have; I never did want the teaching," she told

NASM (9A12028-015E)

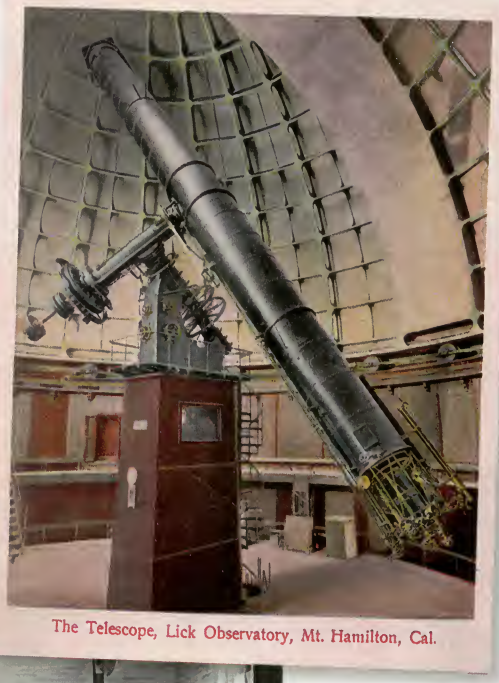
Furness. Although male professors were generally encouraged to pursue independent studies, women were discouraged from devoting time to research over teaching. Without the ability to publish, a woman could rarely move beyond her academic position, or be accepted into the research-oriented U.S. astronomical community.

In 1910, Waterman's boss at the observatory, Mount Wilson director George Ellery Hale, hosted a meeting of the Solar Union, a group he formed to bring physicists and astronomers from all over the world together to organize their research. Waterman was excited to hear about all the science the astronomers were pursuing. She wanted to be part of the next meeting, scheduled for 1913 in Bonn, Germany, and understood that "this means much more physics than I now have, instruction in stellar spectrography, and practical, firsthand knowledge of the spectrograph." She was ready for the next step in her career: "I want to go on now to my Ph.D., and independent work, for I feel that I have gotten from the work here all that it [has] for me."

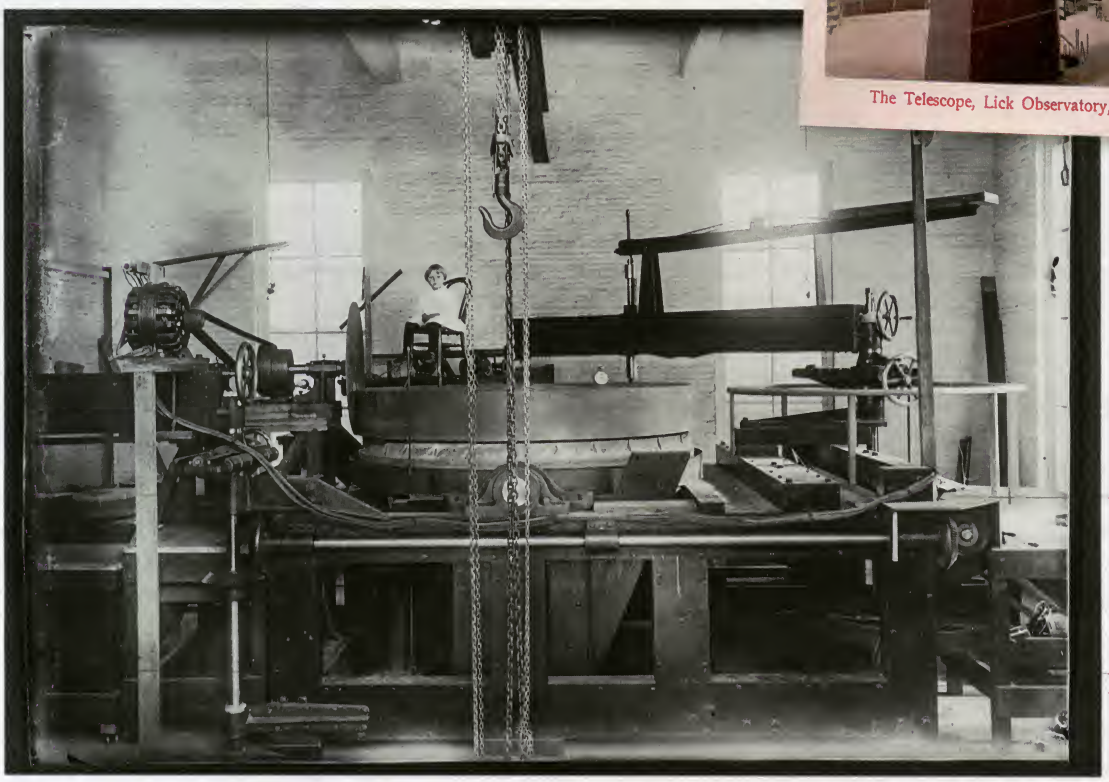
Waterman applied to the doctorate program at Berkeley because at the time tuition was free. Not only was she accepted, but her undergraduate and master's work was so strong that the school awarded her credit toward her Ph.D. in astronomy and mathematics.

When she told the staff at Mount Wilson of her plans, it elicited some surprise: "It is very bold and presuming of a woman to think of such a position I suppose!!" she wrote to Furness in May 1911. "They think so here [at the observatory]." On the other hand, her new colleagues at Berkeley seemed to place as much faith in Waterman as she did in herself. William Wallace Campbell, the director of the Lick Observatory atop Mount Hamilton, south of Berkeley and also operated by the University of California, wrote to Waterman that she seemed well prepared to pursue her doctorate and he would be "very glad to afford all necessary opportunities in the Lick Observatory for practical work in astronomical spectroscopy." Waterman wrote gleefully to Furness about going back to school and being allowed to participate in advancing the field of astronomy: "Hurrah for a little share, just a little one, in the big work you are all busy in!"

When she got to Berkeley, Waterman threw herself into research and classes. She didn't experience the gender divisions that she had at Mount Wilson, explaining that "they give a woman just the same work...as the men, and judge them on the same basis. I am getting used to the different standard a little—for it surely is



The Telescope, Lick Observatory, Mt. Hamilton, Cal.



Being at Mount Wilson was inspiring for Waterman; she took the photo at left of the 100-inch mirror under construction (with a small child for scale). But it was at Lick Observatory (postcard, above) where she was finally allowed to make her own observations.

TOP: NASM ARCHIVES OBSERVATORY POSTCARD COLLECTION; BOTTOM: NASM (9A12028-004A)



50 YEARS OF SKYGAZING

Stare at the sun (safely!) or look at Venus through the telescopes outside the National Air and Space Museum.

IT'S NOT EVERY DAY that a telescope gets a birthday cake. But this telescope was special. It had recently traveled 400 miles to start a new life showing visitors the sky above the National Air and Space Museum in Washington, D.C., and on March 1, 2017, it was turning 50 years old. Half a century ago, its story began with a pianist.

Chester Sheldon Cook earned money for his family in two ways: He gave piano lessons, and he made high-quality optical devices during World War II. A lover of harmony and math, he was naturally drawn to astronomy. So great were his contributions to the Amateur Telescope Makers of Boston that his friends memorialized him when he died by purchasing a large telescope and naming it for him. The Cook Memorial Telescope, built by Boller & Chivens, with a 16-inch mirror, was designed for observing planets, stars, and asteroids. The Harvard-Smithsonian Oak Ridge Observatory bought the telescope in 1967 and for decades astronomy students there used it to study the sky.

When Oak Ridge closed in 2005, Cook's telescope went dark with it. For the International Year of Astronomy in 2009, Smithsonian history of astronomy curator David DeVorkin wanted to put a telescope at the National Air and Space Museum on the National Mall, where more than eight million annual visitors would have access to it. Harvard agreed to loan the telescope to the Museum, with support from the National Science Foundation.

A truck ride and a crane lift later, the Cook Memorial Telescope is now the centerpiece of the Phoebe Waterman Haas Public Observatory. Peering through the observatory's telescope, Museum visitors can observe the phases of Venus, glimpse the moons of Jupiter, or view a projection of the Sun with a special device—which amateur astronomer Cook likely would have appreciated—made from a flowerpot.

When the Observatory's staff and volunteers gathered to celebrate the Cook Memorial Telescope's 50th birthday, we shared stories of its long history and pieces of birthday cake. It's a history you can share too. Check for observing events and updates at airandspace.si.edu/observatory or on Twitter @SIObservatory.

GENEVIÈVE DE MESSIÈRES, ASTRONOMY EDUCATION PROGRAM MANAGER

a different one, and quite a different thing from measuring up against women." Waterman's professors thought, at the time, she was as capable as any man. Armin Otto Leuschner, who ran Berkeley's astronomy program, described Waterman as "one of the most unusually well-equipped women we have ever had at Berkeley. She is brilliant, quick and accurate and disposes of her work with promptness and accuracy."

Over the summer she did research at Lick Observatory for her dissertation. Campbell gave her access to the 36-inch refractor and its world-class spectrograph so she could study whether certain stars could be properly classified using the visible part of the spectrum. She based her work on the Harvard Classification System, then the leading system to catalog stars by their spectra. The classification was organized by astronomer Annie Jump Cannon, who worked with distinguished astronomer Edward Pickering, credited with winning international renown for the Harvard College Observatory. (Cannon, who cataloged over 350,000 stars during her career, was one of over 80 highly talented women, "human computers," who worked with the glass plate observations taken by the male astronomers. Among them was Henrietta Leavitt, who discovered the period-luminosity relationship for stars called Cepheid variables, which could be used to measure distance across space. It was later used by astronomers like Edwin Hubble to calculate the size of the Milky Way, and even the expansion of the universe. The relationship was finally recognized as Leavitt's Law in 2009. The story of the Harvard College Observatory computers was recently told by Dava Sobel in *The Glass Universe*.)

The first part of the classification system was published in 1901, and the astronomers at the 1910 Solar Union meeting—the one that galvanized Waterman to pursue her doctorate—had agreed to conditionally accept the classification system. Waterman's research helped broaden its application, and was a taste of the one thing she really wanted: to make a real contribution to astronomy.

This work was also making Waterman a sought-after astronomer. Before she graduated from Berkeley, in 1913, she received offers for post-graduate work, but only one had Waterman's desire for adventure written all over it. She had persuaded her roommate, Anna Estelle Glancy, to apply with her for positions at the Argentine National Observatory at Córdoba. Glancy wrote later about how it happened. "Phoebe said: 'Let's get jobs at the same observatory.' I answered: 'Who would want two women?' 'Maybe Dr. Perrine would take us,' she said," referring to a Charles Perrine, an astronomer from Lick Observatory who had become the director at Córdoba in 1909. "In a cooperative mood, I said: 'Well, you can ask him.'

ERIC LONG/NASM

Lo and behold, he answered: 'Come.' "

The job offered an exciting opportunity to travel and a salary of $100 a month. But it was much more than that, as Waterman wrote to Vassar professor Mary Watson Whitney: "It is the chance for research which I have been wanting so much; on the astrographic catalog at first, but as soon as they can get their reflector installed, I can have spectrographic work. And just think of the stars down there that have never been touched—I would give almost anything to get at them." On September 6, 1913, Waterman and Glancy left from New York for Argentina.

Life in Córdoba, however, turned out to be a step backward from the freedom she had gotten used to at Berkeley. Women were not allowed to live on the observatory grounds with the male astronomers, so Waterman and Glancy lived in town, and were therefore initially unable to observe at night. "And that's the best part of the whole job, to my mind," Waterman wrote to her colleagues in California, understating the fairly extreme limitation on her ability to perform research. A couple of weeks later, Waterman explained the workaround they'd come up with, which was still difficult "because we have to go up early, before dark, and take chances on its being a clear night." If the sky clouded over, they were stuck—disallowed from traveling at night, with nowhere to sleep on the grounds. Finally Waterman and Glancy requisitioned some cots for their offices at the observatory. Waterman wrote that it felt "good to get into flannel shirt and corduroy, and go up into the dome, to handle the telescope, and to be out with the stars once more!"

After a month of figuring out how to simply do the work she was hired to do, in the face of the observatory's unwillingness to let women share the space properly, Waterman started to see the appeal of another route. On the steamship to Córdoba, Waterman had met a German entrepreneur named Otto Haas and they developed feelings for each other; they wrote letters to each other after parting ways. He had launched the U.S. branch of the chemical company Rohm and Haas, and was on his way to establish branches in South America. Waterman told Haas about her boredom and, as she'd experienced at Mount Wilson, her forced dependence on the work of her male colleagues: "We have finished all the interesting work on our star plates, until they get us some new observations; and now we are just marking time, doing stupid sums all day long. Nights are still fine, of course, but I guess now I am ready to leave it all, and come to you." Waterman asked the observatory to offer her place to another woman, though by the time she left Córdoba two months later and married Haas in Des Moines, Iowa, they hadn't filled it.

Even if Waterman had decided to dig in at Córdoba,

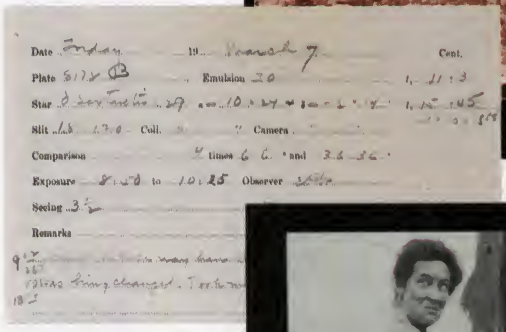


Another path revealed itself on a ship to Argentina, where Waterman, seated, met Otto Haas, top right.

NASM (9A12028-075B)

To Waterman, a career in science meant pursuing not only knowledge but adventure. She photographed the Córdoba observatory under construction (right), rode buckets to the top of the solar tower at Mount Wilson (bottom), and spent satisfying nights using Lick's 36-inch telescope (logbook, center).




Date ... 19... March 7 ... Cent.
Plate ... Emulsion ...
Star ...
Slit ... Coll. ... Camera ...
Comparison ... times ... and ...
Exposure ... to ... Observer ...
Seeing ...
Remarks ...



she likely wouldn't have been allowed to stay upon deciding to marry. Being a wife was considered an occupation, one that conflicted with any work away from home. One revealing exchange about the culture at the time was between Edwin Frost, the head of the University of Chicago's Yerkes Observatory, and Lick director Campbell. While at Berkeley, Waterman had applied for a computer position at Yerkes, before deciding on Córdoba. A year later, after she came back to the States and married, she asked Frost about her application. Frost wrote to Campbell asking about Waterman Haas' qualifications and explained that, though he preferred a man who could participate in observing, he would take a woman. Campbell replied with a glowing recommendation of her skills, describing Waterman Haas as "bright, industrious, and endowed with some elements of originality." But, he added, she "recently changed her occupation" and would no longer be suitable for the position.

(Glancy, the astronomer Waterman Haas left behind in Córdoba, never married, and went on to have a long career in astronomy and optics design.)

Waterman Haas' decision frustrated her female colleagues at Vassar, who wished she had fought harder to both marry and work. Mary Watson Whitney wrote to Furness, "I am disappointed but not surprised to hear of Phoebe's defection.... Why should marriage break all earlier engagements?"

At Lick Observatory, instead of discussing their contribution to the societal pressure that forced women, but not men, to choose between love and a career, her former colleagues used Waterman Haas' decision as an excuse to double down on discrimination. When the Monks, a married couple, applied for fellowships at Lick in 1915, Campbell told Leuschner at Berkeley that his "sentiments concerning Mrs. Monk's desires are...not so favorable" because "Phoebe Waterman's astronomical career lasted about three months after she secured the doctor's degree as a result of your efforts and the opportunities provided here."

TOP: NASM (9A12028-091A); CENTER: LICK OBSERVATORY ARCHIVES; BOTTOM: NASM (9A12028-015C)

Waterman Haas, however, didn't see her marriage as the end of her scientific pursuits. She continued to stay connected to people in the field—and they stayed connected to her, whether they admitted it or not. In March 1914, she requested copies of her doctoral thesis from Lick Observatory. The secretary included a handwritten note: "Your [dissertation] is being used very frequently in the assembly room." Several years later, she noticed a mistake in it, based on observations made by her colleagues. In 1920, she wrote Campbell, explaining that the field of view in some plates had overlapped. She included a manuscript that explained the problem and the calculations she used to measure the spectrum of the star Deneb. Campbell published a corrective note in the Lick Observatory Bulletin, but he did not include Waterman Haas' name.

Because of her expertise in spectroscopy, Waterman Haas had long been fascinated by variable stars—those that change in brightness over time, and can be studied by plotting their light curves. The observations don't require high-powered equipment, so it's a popular area of study for amateur astronomers. The American Association of Variable Star Observers was created in 1911 to collect this data from amateurs and publish it for use by professionals. In 1928, Waterman Haas asked the association to send her a few variable stars to "watch and practice on," describing the brass four-inch Clark telescope with "excellent" glass that she'd recently acquired through her contacts at Lick. She thrived with this outlet for observation and research, writing the association in 1941, "There is nothing I enjoy more than an evening out with my telescope and the thrill of finding a faint prick of light where last time I looked, I could see nothing—then seeing that point brighten. I'll be at it again, yet!"

She was an active member of the association throughout the rest of her life. In 1945, her husband set up a charitable organization in her name, and the Phoebe Waterman Foundation became a crucial financial supporter of the group's work. And Waterman Haas knew first-hand that the volunteer-driven astronomical association could be a refuge for women who couldn't pursue work professionally. She spent much of her time recruiting them to compute the light curves from the vast amounts of data being submitted by observers.

Late in her life, Waterman Haas offered to donate her beloved Clark refractor to the association. Before the association was ready to collect it, she briefly got cold feet, and asked the members if they would postpone the pick-up so she could "get it out while my grandchildren are home for Christmas vacation.... I hope to give them their first look through a telescope." The group postponed the sale, and Waterman Haas was able to spend one more evening with the two things she treasured most: her family, and a telescope that represented a career lost but a joy for discovery that she refused to let go.

Her dedication to astronomy—she also taught the subject at a girls school in Philadelphia almost to the end of her life—eventually impressed some of the people who thought that, while she was capable enough to be awarded a Ph.D., she could not have handled having a family while pursuing science. One of her former Berkeley professors wrote department head Leuschner in 1936, pointing out that Waterman Haas had never "left the field" of astronomy, but had continued observing and doing her own research, in whatever capacity she could: "She has carried her enthusiasms for, and knowledge of astronomy as a powerful cultural influence into her very charming family, and to her friends. In doing so it seems to me that she had fulfilled and is fulfilling the purposes of scientific education quite as effectively as though she were actively engaged in professional work."

That's a legacy that has proved influential far beyond her family and the students she taught. In 2013, Waterman Haas' grandson used his own philanthropic endeavor, the Thomas W. Haas Foundation, to establish an endowment at the National Air and Space Museum in his grandmother's name. The Phoebe Waterman Haas Public Observatory, at the National Mall location in Washington, D.C., honors her contributions to the field of astronomy and her role in advancing the position of women in science. Tom—who inherited his grandmother's sense of adventure, becoming an aviator and flight instructor—wanted to share with others the feeling he had when he looked through her beautiful telescope at the stars. Phoebe Waterman Haas pursued her passions despite the constraints of her era, and now that love of the stars is being passed on to millions of Museum visitors each year who gaze up at the sky because of her.



SUNIL VELUVALI

Waterman Haas might be pleased to hear that today, UC Observatories, which runs the Lick Observatory, where she got her start, is led by astrophysicist Claire Max.

Green Skies

NOISELESS, LOW-EMISSION FLIGHT. COMING SOON TO A SKY NEAR YOU?

by Arielle Emmett



IT TOOK MORE THAN 100 iterations for Israeli physicist Omer Bar-Yohay to declare his company's V-tailed swan of an electric jet ready for the world to see. When his company, Eviation, premiered its drone, the Orca, at the 2017 Paris Air Show, it was a literal glimpse of the shape of things to come. While Eviation intends to market the remote-piloted Orca, it is also using the drone as a one-third-scale demonstrator for the Alice—the nine-passenger crewed electric commuter airplane the Tel Aviv-based firm says will fly next year.

One cent per seat per mile in direct operating costs is the promise Eviation is making with the Alice, designed to soar above cityscapes at 10,000 feet. As with its drone sibling, the Alice sports electric wingtip and tail-fin propeller housings shaped like little bombs. They are attached to a carbon-fiber airframe so light that the aircraft's batteries account for 60 percent of its total takeoff weight.

Bar-Yohay, 39, believes the Alice is the regional jet of the future. Designing it meant rethinking everything.

"People ask me why aren't we using existing aircraft designs—for example, the Piaggio Avanti," Bar-Yohay says, referring to a popular Italian corporate twin turbojet that is easily recognized by the canard, or short fin-like front wing, that makes it look like a hammerhead shark. "It's a great design and I really love it," he says. "But the airframe is built to hold up big shaky aircraft engines."

An electric aircraft needs less structure. "With electric propulsion you have relatively small motors," Bar-Yohay explains, "and this means you can place them in very different locations" than powerplants on a conventional airplane, including wingtips and tail. Using lithium-ion batteries, their power distributed according



LILIUM

Last April in Bavaria, with "less noise than a motorbike," Lilium tested its two-passenger, electric jet prototype, Eagle. Remotely piloted, it took off vertically and transitioned to forward flight.

to a proprietary algorithm, this zero-emission airplane will be able to take off from and land on short runways, like those on the thousands of small, regional airports across the United States.

The Alice is designed to travel up to 650 miles on a single charge at speeds of about 275 miles per hour. Bar-Yohay claims that operators will be able to charge passengers 30 to 60 percent of what they must charge today to operate profitably. If he can sell the Alice for $2.5 million to $3 million per aircraft, he estimates that carriers would need less than four years to recoup their investment through savings on fuel and maintenance costs.

Is he dreaming? Maybe not. After winning acclaim last October at a *Wall Street Journal*-branded global technology conference in Laguna Beach, California, Eviation received what Bar-Yohay calls "a tsunami of interest and investment." He expects the full-size Alice to be test-flown—with a pilot onboard—in 2019.

The advent of lighter and more powerful batteries has drawn a number of entrepreneurs into the electric airplane race. Don Hillebrand, the director of Argonne National Laboratory's Center for Transportation Research, likens the current stage of aircraft electrification to the use of the China Clipper and the other large flying boats built for trans-Pacific flights in the mid-1930s. The internal combustion engine had not matured to a point where it could reliably carry large aircraft that distance without refueling, but there was a consensus that it would. So Pan Am built airstrips and even modest hotels on



Volocopter's Alex Zosel conducts the world's first crewed "multicopter" flight, piloting his firm's VC200 prototype in Karlsruhe, Germany, March 2016.

remote Pacific islands to allow for refueling stops even as the world prepared for the changes that increased trans-Pacific travel and commerce would bring.

Batteries are still not yet good enough to lift heavy airplanes to cruising altitude and keep them there. But designers have seen enough progress to believe they *will* be. "You can almost look at it like the law of incremental improvement," Hillebrand says. "When you continually have a compounded improvement like they're seeing in energy storage technologies, then you really start to think far ahead." And aviation, he points out, is a long game. "Designing a propulsion system 20 years in advance is not crazy, when you look at the complexity of some of the aircraft that are produced now. So now is the time to start planning," he says.

Volocopter has demonstrated an 18-rotor all-electric drone, the Volocopter 2X. The vehicle uses proprietary software to adjust the speeds of 18 separate electric propulsors many times per second.

With smaller aircraft, change is coming much faster.

In 2011, the Taurus G4, made by the Slovenian light aircraft manufacturer Pipistrel, became the world's first electric four-seater to fly. Tine Tomažic, Pipistrel's director of research and development, says his firm's progress in the years since justifies the new optimism. Battery life for the Taurus G4 has grown from 25 minutes to 150 minutes, and cruise speeds from 58 miles per hour to 127. And while the G4 once required six minutes of recharging for every minute of flight time, by 2016 Pipistrel's engineers had reduced the ratio of recharge time to flight time below 1:1. That same year, Pipistrel's HY4 aircraft had its first flight. It's the world's first four-seat aircraft to be powered by hydrogen fuel cells alone. The HY4 can remain aloft for up to 10 hours, emission-free.

"Batteries have improved tremendously in costs and capabilities, electric motors have progressed, and power densities are rivaling gas turbines," says Matt Knapp, founder and aero chief engineer of Zunum Aero. Founded in the Seattle area in 2013, the company intends to begin deliveries of its nine-to-12-seat gas-electric hybrid commuter jet aircraft, the ZA10, in the early 2020s. The charter airline JetSuite is Zunum's first customer, having announced plans to

VOLOCOPTER



Technicians attach rotor blades to the VC200 in Volocopter's hangar in Bruchsal, Germany. The "multicopter" uses proprietary software to adjust the speeds of 18 individual rotors several times per second.

NIKOLAY KAZAKOV/VOLOCOPTER

buy up to 100 of Zunum's new airplane.

Both Zunum and Eviation say their electric aircraft will take advantage of underused public airports. They believe that if they can spare passengers the burden of connecting through hubs to reach smaller cities, customers will show up.

In March 2017, Zunum secured investment from two big players: Boeing HorizonX and JetBlue Technology Ventures. Both companies are betting that electric or hybrid electric jets are the key to more profitable regional and intercity flight.

"Today's regional jet-size aircraft are not cost-efficient," says Bonny Simi, president of JetBlue Technology Ventures. (She flies a regional jet herself, the 100-seat, 515-mph Embraer 190.) She maintains that for electric fixed-wing aircraft with 10 to 50 seats, the current market "sweet spot" is 300 to 1,000 miles. Operators measure their costs by available seat mile (ASM), or the cost to carry one seat one mile.

"Jet aircraft are more efficient the longer and higher they fly" and the more seats they carry, Simi explains. On long trips, big jets with seat numbers in the triple digits have an operating cost of $0.08 to $0.12 per ASM. For short trips, jets are more costly because more fuel is burned during takeoff and climb, and fixed costs are shared over fewer miles. Some carriers now use turboprop aircraft for shorter flights, which have an ASM of $0.15 to $0.20. But down into the 10-seat range, ASM spikes above $0.40.

"The cost for battery power is much less than the cost of fuel, and there is less maintenance," Simi says. "Forecasts for electric aircraft [flying] 300 to 700 miles estimate 10 to 12 cents," a fraction of the cost for airplanes with fewer than 50 seats.

JetBlue Technology Ventures has focused on small electric airplanes because they believe there's a limit to how good batteries will get in the near term. "Battery powered airplanes will max out at 50 seats and 1,500 miles," Simi predicts. "We don't see anything bigger or longer for the next 50 years."

VERTICAL INTEGRATION

Vertical takeoff and landing is the hottest area of development in the pursuit of small, electric aircraft. Lilium of Munich, for example, has already tested a fully electric VTOL mini-jet—a remote-piloted, two-seat white pod that launches from a landing pad but flies like a conventional airplane. It can cruise at 187 mph and fly for one hour on a battery charge.

The German company promises quiet, zero-emission air taxis for up to five passengers, summoned on demand via a phone app. "We believe in a world in which everyone can fly anywhere, anytime," says Lilium co-founder and CEO Daniel Wiegand in a slick marketing video created to promote the venture.

So far his pitch is working: Lilium has raised $100 million from billionaire investors like Skype co-founder Niklas Zennström, Chinese tech giant Tencent, and Obvious Ventures' Ev Williams, who

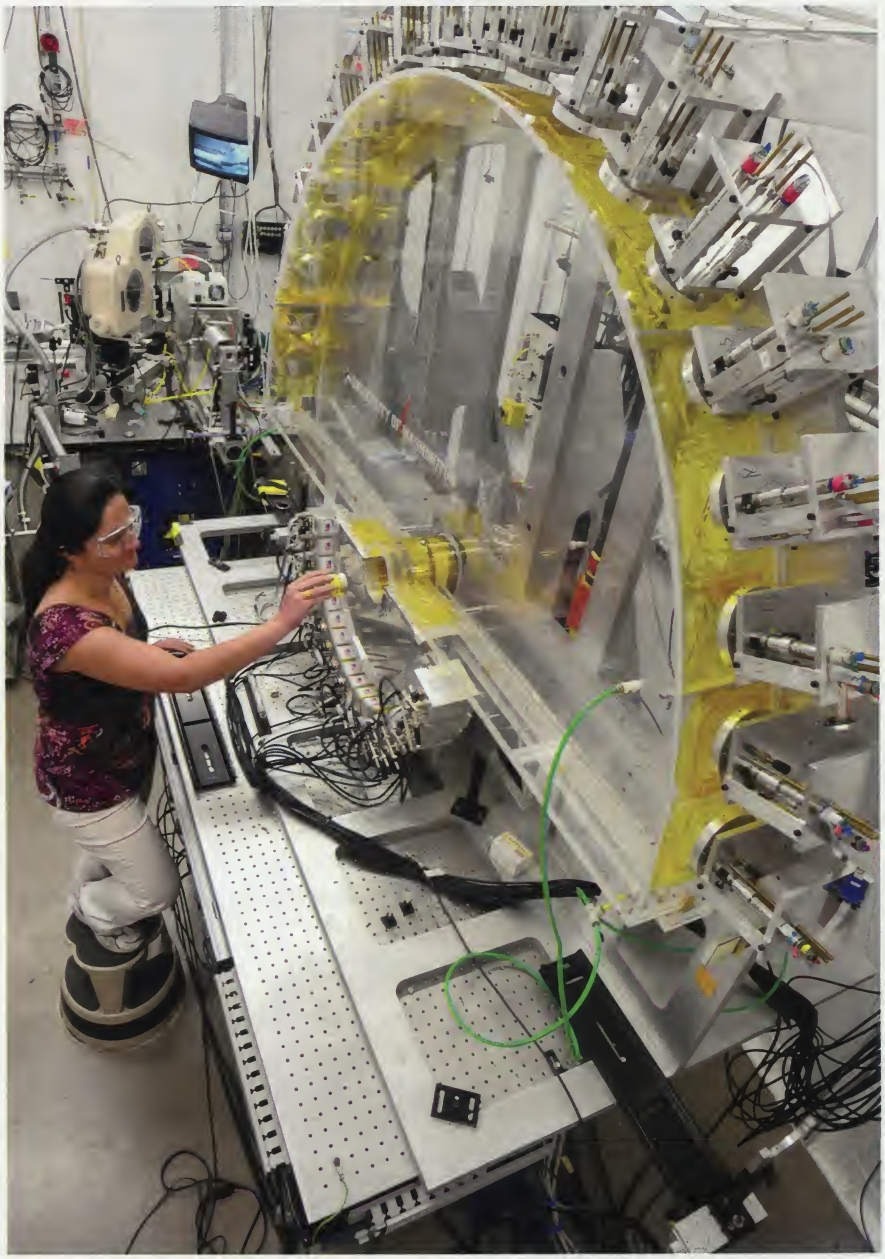
also co-founded Twitter and served as its CEO until 2010.

But Lilium isn't even the only German company in this sphere. Volocopter has demonstrated an 18-rotor all-electric drone, the Volocopter 2X. (Intel CEO Brian Krzanich was its first passenger, in December 2017.) The vehicle uses proprietary software to adjust the speeds of 18 separate electric propulsors many times per second.

Others will come. According to BIS Research, the worldwide market for fixed-wing VTOLs reached nearly $2 billion in 2016. Those numbers will hit $5.3 billion by 2026, thanks to both civilian demand and a military need for high-speed VTOLs.

One of those military specimens was the Defense Advanced Research Projects Agency's LightningStrike XV-24A. The aircraft, which was cancelled in April, was a hybrid electric uncrewed VTOL with a three-megawatt turboshaft engine powering 24 ducted fans, nine integrated into each wing and three inside each canard. Both the wings and the canards rotated to direct fan thrust aft for forward flight or downward for hovering. Announcing the cancellation, a DARPA spokesperson said the XV-24A had achieved its major design objectives as a subscale demonstrator. No private-sector transition partner for the VTOL has yet been named.

At Argonne National Laboratory outside Chicago, researcher Swati V. Pol inserts a lithium-ion battery into an X-ray device to study how to increase its capacity.



ARGONNE NATIONAL LABORATORY

The civilian sphere, meanwhile, is heavily invested in Short Take-Off and Landing aircraft. Faradair Aerospace Limited, a U.K.-based aviation design firm, is developing a six- to eight-seat, boxed-wing "bioelectric hybrid aircraft"—founder Neil Cloughley calls it BEHA. Intended as a more readily achievable alternative to fully electric flight, BEHA uses batteries just for takeoffs and landings and as a safety backup to an internal combustion engine that burns Jet A or biofuel at cruising speed.

Cloughley is keeping his promises modest: A minimum 10 minutes of electric flight from the prototype he expects to have ready in 2020 or 2021. The BEHA has a shrouded-duct propeller in the rear to capture sound. Cloughley believes the design will eventually be "faster than a helicopter" and cheaper to buy and to operate.

He hasn't yet made that pitch to the public. Faradair is relying on private investment for now, while acknowledging that final certifications under the Federal Aviation Administration and the European Aviation Safety Agency could take "a couple of years." Which will still bring it to fruition faster than any electric-only aircraft, in his view. "If anyone thinks they're honestly going to build a [large] electric aircraft and get it certified in 10 years, they're mad," he says.

Cloughley is taking a shot at the British discount airline easyJet there. In April 2017 easyJet made a splashy announcement with Wright Electric, a U.S. start-up, pledging to build a fully electric aircraft capable of carrying at least 120 passengers within a decade.

Gary Smith, easyJet's head of engineering, says that only major emissions reductions and cost savings can make the economics of short-haul flights make sense. "We need a robust, reliable aircraft that can perform with turnaround times of 25 minutes," he says. "If you're going to

eliminate gas turbine engines, the aircraft should be electric and digital."

The business intelligence firm Thomson-Reuters estimates that if electric jets were proven, the market could reach $22 billion within 15 years. But proving them will require a battery that can rival the power density of fossil fuels.

No one yet knows how to build one.

JUICING UP

The oft-cited magic number at which long-distance battery-powered commercial flight might become viable is 1,000 watt-hours produced per kilogram of battery weight. That's a long way from existing batteries, which have specific energy in the range of 270 to 300 watt hours per kilogram, says Venkat Viswanathan, a professor of mechanical engineering at Carnegie Mellon University in Pittsburgh. He personally doesn't buy the 1,000 watt-hours per kilogram minimum; he says that with new techniques in drag reduction, batteries that supply even half that much power would make electric flight "really competitive." He asserts that a battery producing "only" 400 to 500 watt-hours per kilogram could propel an airplane 200 to 400 miles on a single charge.



Seattle's Zunum Aero intends to have its nine-to-12-seat, gas-electric hybrid ready to compete in the commuter jet market early in the 2020s.

Results like that might not be enough to convince skeptics that we should entrust machines as complex and potentially dangerous as aircraft to battery power at all. But even inventing a battery powerful enough to carry that much energy wouldn't solve the problem of how to generate enough power to charge it.

Alan Epstein, vice president of technology and environment at Pratt & Whitney, says that an aircraft the size of an Airbus A380 running purely on batteries would require charging for "half an hour using most of Connecticut's available electric power." He sees no compelling argument for trying to build electric versions of such massive, power-hungry machines when "conventional planes just keep getting better." (It must be said that no manufacturer has announced plans to attempt an electric or hybrid-powered aircraft the size of the A380, the world's largest airliner.)

Argonne's Hillebrand disputes that traditional engines will preserve their lead. "Internal combustion aircraft engines continue to improve, but they're not improving at the rate that battery density and power electronics are improving," he says. "It's a bit of a race, and [electrics are] way behind and moving much faster."

Gregory Bowles, vice president of global innovation and policy at the



According to Faradair Aerospace, its hybrid triplane, BEHA (artist concept, below), will be faster, cheaper, and quieter than a helicopter.

TOP: ZUNUM AERO; BOTTOM: FARADAIR



At the 2017 Paris Air Show, Eviation's all-electric Orca drone showed off the design the firm intends to use in its crewed Alice commuter jet, which it says will fly in 2019.

General Aviation Manufacturers Association, is confident the power generation challenge will be solved. "A person from the late 1800s might make the same claims about replacing gas lamps with light bulbs: that a grid to supply electricity for bulbs doesn't exist," he says. He points out that power generation will have to increase whether electric airplanes come or not. "Electricity is so important in the future world, these issues are far greater than aviation," he says.

carbon footprint (12 percent of the total carbon emission from all transportation sources). The worst carbon polluters are the electric utilities still operating on coal and natural gas. Electricity generation accounts for 29 percent of greenhouse gas emissions worldwide, while cars, trucks, diesel engines, and trains account for 27 percent.

Aviation may benefit from investments by automakers, who have been pushing the development of lithium-ion

"Internal combustion aircraft engines continue to improve, but they're not improving at the rate that battery density and power electronics are improving," says Argonne's Don Hillebrand.

One of the benefits of electric power generation is emissions reduction. Airplanes release 500 million tons of carbon dioxide into the atmosphere each year; unless major new restrictions are put in place, that figure is expected to triple by 2050. The International Civil Aviation Organization says the emissions argument for trying to replace combustion engines with hybrid or electrics is comparatively weak because aviation accounts for only two percent of the globe's total

batteries. But there's an ecological cost to that too. Making these batteries involves rare earth mining, which releases toxic aluminum sulfate and sulfuric acids into the environment.

Richard Aboulafia, a vice president with the Teal Group, an aviation market research firm, doesn't see this market evolving without governmental pressure. In the United States, "there is no regulatory or cost impediment at present related to aircraft emissions," he says, although Europe is tightening rules with a carbon cap-and-trade program. "Electric will only succeed in a market if it enables aviation to do something it currently can't do," he says. He even doubts the strategy of using smaller electric aircraft to revive underutilized public airports. "The airfields are underutilized because they are places that people don't want to go," he says. Further, the projected costs to operate the upcoming generation of electrics may not be any cheaper than conventional aircraft incur. He argues that even for intercity flight, electric VTOLs and air taxis will cost passengers about the same as helicopter rides, unless they become ubiquitous. So why not stick with time-tested technology?

HALF AND HALF

Glenn Llewellyn, the general manager for electrification at Airbus, concedes that it all comes down to dollars and cents. But he says Airbus has seen sufficient progress to make investments in hybrid electric flight. It started in 2014 with the flight of the E-Fan, a tiny two-seater powered by two 30-kilowatt electric engines, followed by more powerful electric E-Fan flights across the English Channel. Airbus cancelled its plans to bring the E-Fan to market this year, but Llewellyn says that once Siemens assured its partner it could build a two-megawatt motor "at the right power-to-weight ratio," Airbus was convinced it should continue development of the E-Fan.

In late 2017, Airbus announced it would partner with Rolls-Royce and Siemens to build a hybrid electric aircraft demonstrator, the E-Fan X hybrid, scheduled to fly by 2020. Developed from a BAe 146 regional airliner, one of the demonstrator's four gas turbine engines will be replaced by a two-megawatt electric motor powered by batteries. Eventually a second electric motor will be installed.

Llewellyn says that Airbus perceives a pathway for better batteries: hybrids at first, mostly kerosene burning, then gradually introducing electric power as gas turbines get swapped out. Modular design and boundary layer ingestion are important developments too.

"When you start to separate power

OIDA STRATEGIC INTELLIGENCE

generation from thrust generation," as is possible with electric power, "you have much more flexibility in overall design, including smaller vertical tails," Llewellyn says. For example, "if we have distributed propulsion mounted on the wings—six or more propellers—these could be used for differential thrust, providing yaw control and therefore eliminating the need for a vertical tail. Distributed propulsion is a lot easier with electric motors because they are lighter weight and lower cost than adding multiple gas turbines along the wing," he says.

Airbus's partner, Siemens, experienced a tragic setback on May 31 when another aircraft for which it had built an electric motor, the Magnus eFusion, crashed near Magnus's headquarters in southern Hungary. Both pilots were killed in the accident, the cause of which is currently under investigation.

In 2008, Boeing began work on an advanced concept hybrid jet, the SUGAR Volt. (SUGAR stands for Subsonic Ultra-Green Aircraft Research.) The goal of the study was to reduce noise, environmental impact, and fuel consumption by 70 percent within 20 years.

The Volt has not been built. But Boeing spokesperson Megan Hilfer says the design process has produced meaningful innovations, like the high-span, truss-braced wing with battery pods mounted beneath it. Its wings fold up on the ground like those of carrier-based aircraft. This Volt's hybrid powerplant covers long-range flights with conventional fuels and shorter flights primarily with electric power.

Zunum's ZA10 model is a bit like the Volt: It uses both gas turbine and plug-in electric power to run on less than half the fuel consumed by a conventional turboprop, producing about one-quarter of a turboprop's noise. Its dual propulsors, in the rear of the aircraft, are ducted fans driven by electric motors, the power coming from a combination of batteries and the gas turbine generator.

The interesting aspect of the Zunum model is how conservative most of it is: Zunum's Matt Knapp says the major innovations are the hybrid electric powertrain, coupled with an airframe optimized for regional speeds and distances. The cockpit, propellers, and airframe designs and materials are standard; pilots and mechanics will need very little retraining.

If Zunum hits its targets of beginning deliveries in the early 2020s, Knapp says that among the first to benefit will be weary frequent fliers who'll get to begin to travel from underused public airports. "As just one example, Moses Lake in Washington state has gained and lost air service several times in the past decades," Knapp says. "They put up the funds to build a nice air terminal but haven't been able to keep air service at a self-sustaining cost."

Passengers may like the idea of driving to smaller airports—or they may not. And though Zunum, Eviation, and others will continue to claim they can move passengers to their destinations twice as fast for half the money, the dire condition of our electrical infrastructure could still turn their business plans to dust.

No one knows how electric flight will evolve. That's the reason the industry has so many technological irons in the fire, says Steve Nordlund, a vice president with Boeing HorizonX. As for timetables, "everyone's predictions are just that: predictions," he says. But he's optimistic. "We are watching to see how electric innovation happens over the next several years to see if it's viable. We truly believe it is."

SIEMENS

The Siemens-powered Magnus eFusion hybrid aircraft makes its maiden flight over Hungary, April 2018. The eFusion is now grounded following a fatal crash on May 31.



Sightings

PICTURES WORTH A SECOND LOOK

THE BONEYARD MIGHT BE a place airplanes go when they die, but these photographers have a talent for bringing them back to life. The annual meeting of the International Society for Aviation Photographers took place last March at the Pima Air & Space Museum, known for its massive boneyard housing more than 4,000 retired aircraft on the Arizona desert sands.

ISAP member Rod Reilly saw this Sikorsky CH-37B Mojave helicopter (below) from a distance as the sun was setting. He broke into a run to get there in time to capture "the warm light falling on the Army olive drab paint scheme, the darkened abstract shadows of other helicopters cast on the Mojave's bulky fuselage, and most importantly the iconic Saguaro cactus"—the only one he could find on the grounds near an aircraft.

Jo Hunter wasn't looking for desert romance. The dismantled wing of a Douglas







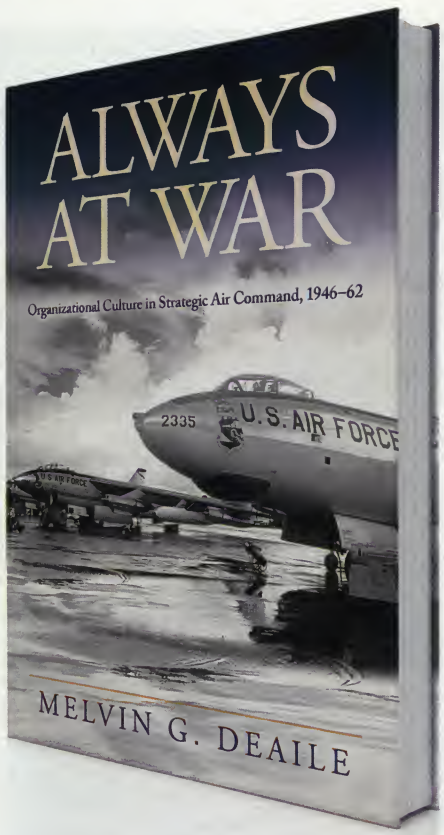
C-54 Skymaster (above) is more evocative of the rough life and ignoble end for some military aircraft. "I was drawn to the array of textures and shapes of all the parts," Hunter says, "the weathering of the wing surfaces, the aircraft behind that shows the context, and the harsh desert light."

An unfulfilled mission is what Carl Wrightson saw in this Fairey Gannet AEW.3 (opposite, top). It was designed to be part of the Royal Navy's airborne early warning system on aircraft carriers, but the idea for the system and the carrier it would operate on were both scrapped. The Gannet nonetheless served for two decades, and here Wrightson highlights the airplane's strange components, from the inverted widow's peak of its canopy to its egg-like radome and contra-rotating propeller. Wrightson thought as he looked at it through the lens: "As the sun set and the sky turned pink behind it, from a distance it looked like it was alive again."

WHEN BOMBERS RULED

Always at War: Organizational Culture in Strategic Air Command, 1946–62

by Melvin G. Deaile. Naval Institute Press, 2018. 296 pp., $34.95.



THE BOOK The author, a retired U.S. Air Force colonel who flew bombing missions during Desert Storm, has written a history of the Strategic Air Command, providing a detailed examination of the organization's deterrent role during the cold war.

> **"Initially, SAC crews lived in barracks close to the runway, but in 1959 the Air Force gained the money to build another artifact of SAC culture: the alert facility. [They] were to be comfortable and have adequate living space to provide not only sleeping quarters but also places for crews to enjoy television, games, and special alert cooking."**

WHY THE AUTHOR DECIDED TO WRITE IT My research into the Strategic Air Command initially grew out of simple curiosity. After completing the Air Force Academy and pilot training, the Air Force assigned me to fly a B-52 Stratofortress in SAC at Barksdale Air Force Base in Louisiana. Later in my career, in 2004, the Air Force sent me to the University of North Carolina-Chapel Hill to pursue a doctorate, and I took that opportunity to delve into the origins of SAC.

A CHAT WITH MELVIN DEAILE

How would you describe the culture of SAC?

When General [Curtis] LeMay first took over, he wanted to assess the readiness of the organization. In January of 1949, he flew every bomber in SAC against a target he picked out near Wright Field in Dayton, Ohio. Not one bomber successfully completed the mission. With the organization's attention, LeMay told the command they were no longer preparing for war, but they were "at war." This is the origin of the book's title. Every day that SAC members came to work, they were at war.



Dealle teaches at Air Command and Staff College.

What are some of the challenges the Air Force faced during the cold war?

Securing a prominent role for strategic bombers and atomic weapons in national security meant that other Air Force missions—especially close air support—suffered for lack of funding and emphasis. Although the nation was preparing for the big nuclear fight with the Soviet Union, the Air Force had to support ground troops who were actually fighting proxy wars in Korea and Vietnam.

What is your opinion of Curtis LeMay?

The strength of LeMay was his ability to command. He organized, trained, and equipped airmen to become a credible enough deterrent so that the cold war never went "hot." He understood the importance of the mission, and he got buy-in from those under him.

DIANE TEDESCHI IS A SENIOR ASSOCIATE EDITOR AT *AIR & SPACE/SMITHSONIAN*.

Read the entire interview at *airspacemag.com/deaile*

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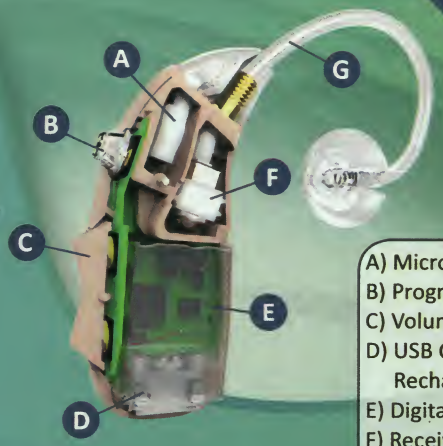
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Moonshots **(above) offers views of Buzz Aldrin on his Gemini 12 spacewalk (left); Apollo 17's Harrison Schmitt walking on the moon (below); the recovery of the Apollo 13 capsule after splash-down (bottom).**





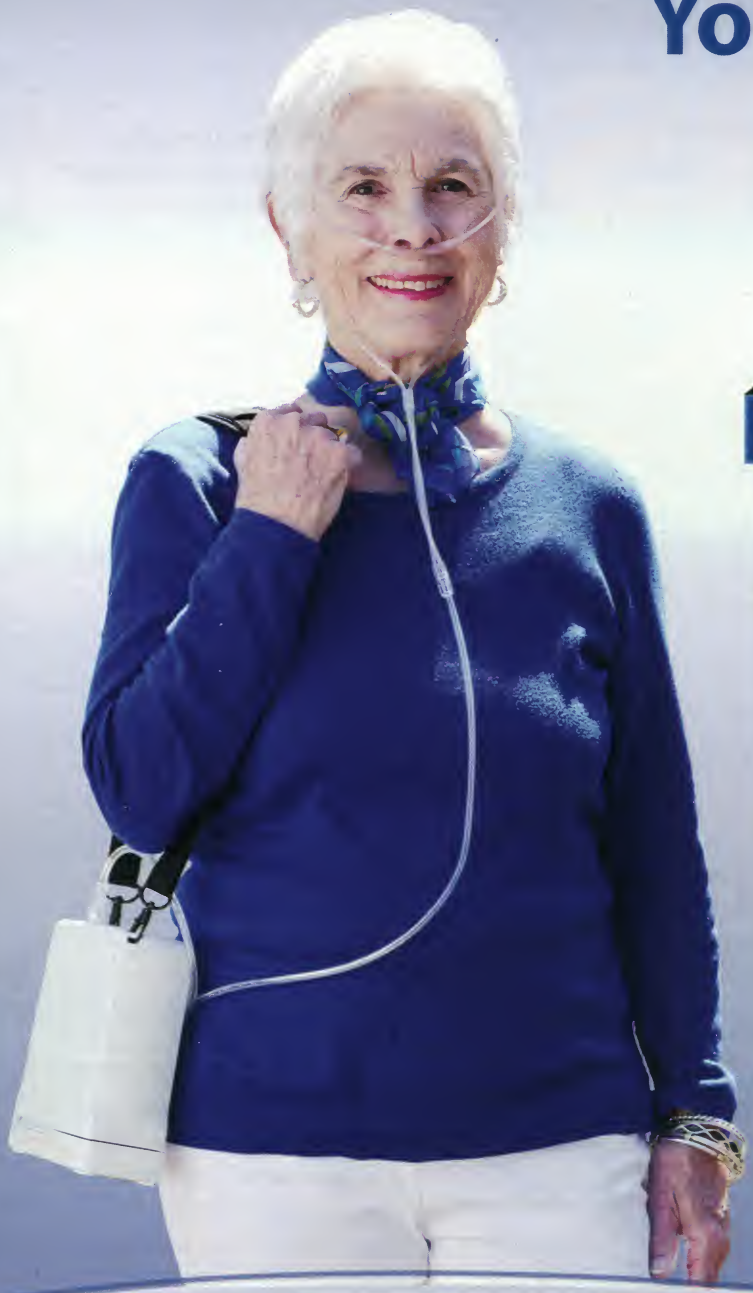
JSC/NASA (3)

Moonshots: 50 Years of NASA Space Exploration Seen Through Hasselblad Cameras

by Piers Bizony. Voyageur Press, 2017. 240 pp., $75.

AFTER COMBING THE ARCHIVES of NASA, author Piers Bizony selected more than 200 images for *Moonshots*. The high-resolution photographs, richly printed on heavy stock, reveal the stunning visual nature of human space exploration: the barren beauty of the moon, the jewel-like glow of Earth from afar, a buzz of activity in mission control, the architectural lines of the space shuttle, and the imposing mass of the space station. The book will be treasured by space enthusiasts.

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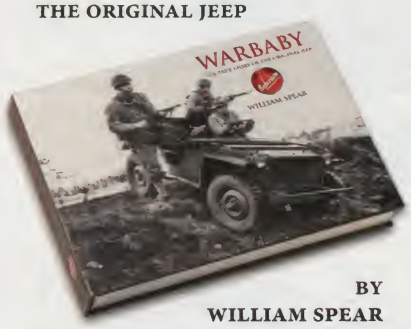
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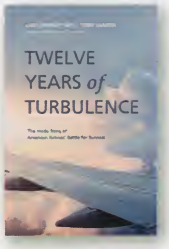
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Twelve Years of Turbulence: The Inside Story of American Airlines' Battle for Survival

by Gary Kennedy with Terry Maxon. Savio Republic, 2018. 220 pp., $26.

THE PRINCIPAL AUTHOR served for part of this saga as general counsel for American Airlines, and his co-author is a reporter who covered American for the *Dallas Morning News*. As the reader might expect—or should—this is an account of events at American Airlines preceding its merger with US Airways in 2015, limned for the most part with one attorney's perspective on a series of events.



During the entire period, American was losing money by the 747-load. Kennedy had worked his way up to the general counsel's office, and throughout his experience there, the company's management team faced one crisis after another, including 9/11 and the crash of Flight 587. American had a well-earned image as a conservative airline, but one that had pioneered the frequent flier rewards concept, an innovation that was universally copied—and used to this day.

The airline also had a reputation for taking a tough line in its labor relations, and unions representing such trades as pilots, flight attendants, and ramp workers, among others, were almost never in harmony with management, which blamed labor costs for its inability to compete. The distrust between the two sides is palpable in this account.

In the end, American's survival was in name only. US Airways was the big winner in this merger, and the author didn't make the team.

GEORGE C. LARSON IS THE FOUNDING EDITOR OF *AIR & SPACE*.

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- Laser guide

Customer Rating ★★★★★



NOW $129.99

$179.99

COMPARE TO $249 RYOBI MODEL: TSS120L

SAVE $119

Blade sold separately.

ITEM 61970/69684/61969 shown

20386651

LIMIT 5 - Coupon valid through 11/24/18*

CENTRAL PNEUMATIC — SUPER COUPON

3 GALLON, 100 PSI OIL-FREE AIR COMPRESSORS

Customer Rating ★★★★★

A



B



A. HOT DOG ITEM 69269/97080 shown

B. PANCAKE ITEM 60637/61615 95275 shown

- Air delivery: 0.6 CFM @ 90 PSI, 1 CFM @ 40 PSI

SAVE 59%

YOUR CHOICE $39.99

$54.99

COMPARE TO $98.62 PORTER-CABLE MODEL: PCFP02003

20388445

LIMIT 4 - Coupon valid through 11/24/18*

U.S. GENERAL SERIES 2 — SUPER COUPON

30", 4 DRAWER TECH CART

- 12,600 cu. in. of storage
- 580 lb. capacity
- Heavy duty gas struts hold lid open at 90 degrees

NEW



NOW $99.99

Customer Rating ★★★★★

$149.99

COMPARE TO $799.95 SNAP-ON MODEL: KR8C10TBPC

SAVE $699

Side tray sold separately.

ITEM 64096

20388657

LIMIT 3 - Coupon valid through 11/24/18*

BADLAND Battle Tested — SUPER COUPON

2500 LB. ELECTRIC WINCH WITH WIRELESS REMOTE CONTROL

- Weighs 14.3 lbs.
- 11-1/8" L x 4-1/2" H

Customer Rating ★★★★★



NOW $49.99

$69.99

COMPARE TO $189.99 SUPERWINCH MODEL: 1125220

SAVE $140

Voted Best Winches

ITEM 61840/61297/63476/61258 shown

20391181

LIMIT 5 - Coupon valid through 11/24/18*

WARRIOR — SUPER COUPON

29 PIECE TITANIUM DRILL BIT SET



Customer Rating ★★★★★

NOW $9.99

COMPARE TO DEWALT $64.99 MODEL: DW1359

SAVE 84%

ITEM 62281 61637 shown

$17.99

20395523

LIMIT 9 - Coupon valid through 11/24/18*

EARTHQUAKE — SUPER COUPON

1/2" HEAVY DUTY COMPOSITE PRO AIR IMPACT WRENCH

950 FT. LBS. TORQUE BOLT BREAKAWAY



NOW $89.99

- Weighs 5 lbs.

Customer Rating ★★★★★

ITEM 62835

$114.99

COMPARE TO $249.99 CHICAGO PNEUMATIC MODEL: CP7745

SAVE $160

20401498

LIMIT 4 - Coupon valid through 11/24/18*

COVERPRO — SUPER COUPON

10 FT. x 10 FT. PORTABLE SHED



Customer Rating ★★★★★

NOW $139.99

ITEM 63297

COMPARE TO $236.89 SHELTER LOGIC MODEL: 70333

SAVE $96

$159.99

20402610

LIMIT 5 - Coupon valid through 11/24/18*

HaulMaster — SUPER COUPON

- 1000 lb. capacity

18" x 12" MOVER'S DOLLY



Customer Rating ★★★★★

NOW $7.99

COMPARE TO BUFFALO TOOLS $17.65 MODEL: HDFDOLLY

SAVE 54%

$10.99

ITEM 61899/63095/63096 63098/63097/93888 shown

20422634

LIMIT 9 - Coupon valid through 11/24/18*

SUPER COUPON

7 FT. 4" x 9 FT. 6" ALL PURPOSE/WEATHER RESISTANT TARP

Customer Rating ★★★★★



NOW $2.99

SAVE 70%

COMPARE TO $9.98 BLUE HAWK MODEL: 8G8X10-Y

$4.99

ITEM 69249/69115/69137/69129/69121/877 shown

20403634

LIMIT 7 - Coupon valid through 11/24/18*

CENTECH — SUPER COUPON

2/10/50 AMP, 12 VOLT BATTERY CHARGER/ ENGINE STARTER

Customer Rating ★★★★★



NOW $29.99

SAVE 50%

$49.99

COMPARE TO $59.99 SCHUMACHER ELECTRIC MODEL: SE-1250

ITEM 60581 60653 shown

20404973

LIMIT 4 - Coupon valid through 11/24/18*

SUPER COUPON

.50 CAL METAL AMMO CAN



Customer Rating ★★★★★

NOW $12.99

$15.99

ITEM 63750/63181 shown

COMPARE TO $24.99 GAME WINNER MODEL: FSGWHE1030

SAVE 48%

20408106

LIMIT 6 - Coupon valid through 11/24/18*

PITTSBURGH AUTOMOTIVE — SUPER COUPON

ATV/LAWN MOWER LIFT

Customer Rating ★★★★★



NOW $74.99

- 300 lb. capacity
- Weighs 72.5 lbs.

$89.99

ITEM 60395/62325 62493/61523 shown

SAVE $67

COMPARE TO MAX LOAD $142.08 MODEL: 38028

20413219

LIMIT 5 - Coupon valid through 11/24/18*

PITTSBURGH — SUPER COUPON

40 PIECE, 3/8" DRIVE SAE AND METRIC SOCKET SET

Customer Rating ★★★★★



LIFETIME WARRANTY

NOW $3.99

COMPARE TO $19.97 KOBALT MODEL: 89809

SAVE 80%

$4.99

ITEM 63015/61328/47902/62843 shown

20417459

LIMIT 9 - Coupon valid through 11/24/18*

drill master — SUPER COUPON

80 PIECE ROTARY TOOL KIT

Customer Rating ★★★★★



NOW $6.99

$9.99

ITEM 63292/63235/68986/97626 shown

COMPARE TO $26.35 PROFESSIONAL WOODWORKER MODEL: 51832

SAVE 73%

20419374

LIMIT 8 - Coupon valid through 11/24/18*

CHICAGO ELECTRIC WELDING — SUPER COUPON

125 AMP FLUX-CORE WELDER

Customer Rating ★★★★★



EVERYTHING YOU NEED TO WELD

NOW $99.99

$109.99

ITEM 63583/63582 shown

COMPARE TO $129.99 IRONTON MODEL: 45433

SAVE $30

20420425

LIMIT 3 - Coupon valid through 11/24/18*

GREENWOOD — SUPER COUPON

1-1/4 GALLON HOME AND GARDEN SPRAYER

Customer Rating ★★★★★



NOW $8.99

$12.99

COMPARE TO ROUNDUP $18.71 MODEL: 190315

SAVE 51%

ITEM 63124/63145/95692 shown

20421153

LIMIT 7 - Coupon valid through 11/24/18*

*Original coupon only. No use on prior purchases after 30 days from original purchase or without original receipt. Valid through 11/24/18.

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Contributors

Solar System Chatter. Heather Goss is the departments editor at *Air & Space/Smithsonian*.

What Keeps Pilots Up at Night. Nicole Scherer is a U.S. Navy helicopter pilot from Malvern, Pennsylvania. Her dad taught her that flying is an art, not a science; her mom reminded her to write it all down.

A B-17 Came to Roost in Oregon. Preston Lerner is a frequent *Air & Space* contributor.

Shark Spotter. Chris J. Bahnsen has written about sharks, seals, and sea turtles of the Eastern Pacific for over a decade.

World's Fastest Piston-Power Airplane. Photographer and writer Scott Germain (*lightandlift.com*) has worked on Unlimited race teams and covered air racing since 1986.

Our New Planet Hunter. Rebecca Boyle is a freelance journalist based in St. Louis, Missouri. She is a contributing writer for *The Atlantic*.

Astronauts, Your Ride's Here! Tony Reichhardt is the *Air & Space* senior editor.

Where's the Prop? David Sears is a New Jersey-based writer and historian. He has been named *Naval History* magazine's 2017 author of the year.

Devoted to the Stars. Melissa Joskow is a recent graduate of Wesleyan University in Middletown, Connecticut. She is a former summer research assistant at the Smithsonian Institution's National Air and Space Museum.

Green Skies. Arielle Emmett is an *Air & Space* contributing editor.

Forecast IN FUTURE ISSUES

Uber to Orbit



SUIT UP AND STAND BY Astronaut Sunita Williams (above) will be one of the first to experience Boeing and SpaceX space taxis. How does this charter change her job?

NORAD at 60



KEEPING WATCH for 60 years, NORAD is still looking outward. Since 9/11 the agency has also looked inward, adding air patrols by F-16s (above) and other fighters to ensure the safety of North America.

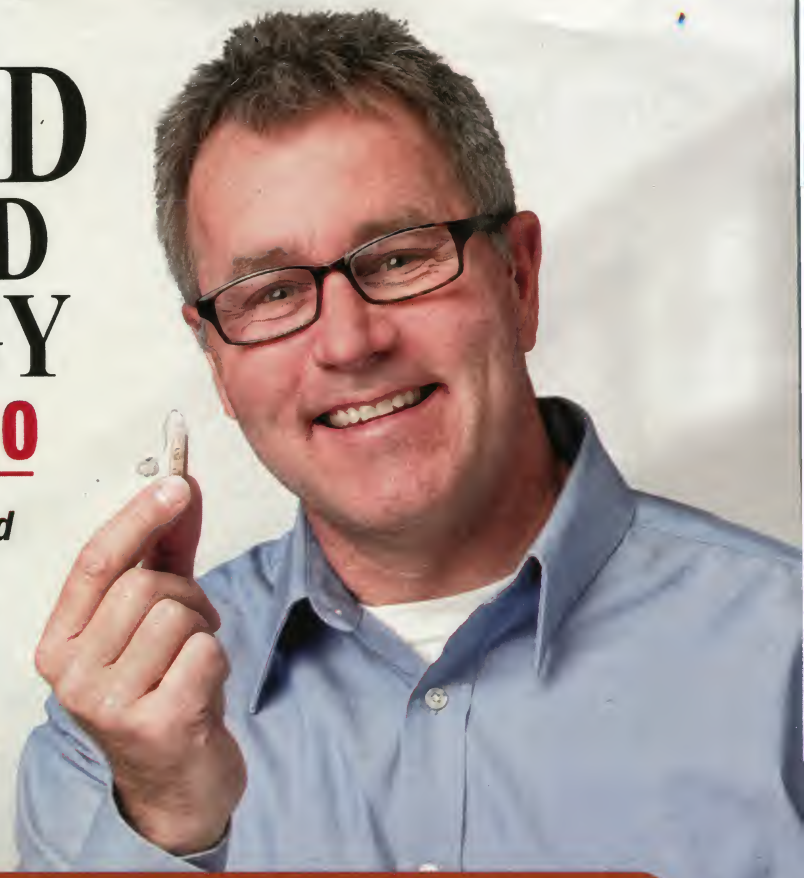
Flights of Fancy

HAVE FLYING CARS finally arrived? New computer and propulsion technologies—and new business models—suggest that they're close.

TOP: MARK HARRIS; BOTTOM: USAF

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— Don W., Sherman, TX

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One More Thing

FACTS ABOUT ARTIFACTS IN THE NATIONAL AIR AND SPACE MUSEUM



Extra 260 Aerobatic Aircraft

What made Walter Extra's aerobatic monoplane so maneuverable? It was designed for instability.

IN SEPTEMBER 1991, when Patty Wagstaff became the first female National Aerobatic Champion since the men's and women's categories were merged in 1972, the airplane she won (and then defended) the title in was hand-built and one of a kind.

Its designer, Walter Extra, had flown a Pitts biplane in the World Aerobatic Championships nine years earlier. He had grown frustrated at the limitations of that design while marveling at the performance of new variations on the Stephens Akro monoplane.

The Extra 260 was his elegant blend of classical and high-tech materials, boasting a steel-tube fuselage and wings made of Polish pine box spar and solid ribs, covered first in birch plywood, then in Ceconite fabric. The wing is equipped with an almost full-length, carbon fiber aileron. While most aircraft are designed to resist slips and skids by rolling against them, the 260 is optimized for lateral instability, making it exceptionally agile and responsive to a pilot's commands. Sighting devices on each wingtip allowed the pilot to judge her attitude relative to the horizon. (Gyroscopic attitude indicators are often temporarily scrambled by extreme aerobatic maneuvers.)

The 260's Textron Lycoming AEIO-540-D4A5 engine has been modified to breathe in more air than a conventional 540's six cylinders do, and airflow among those cylinders is balanced for maximum performance.

After winning her second National Aerobatic Championship in the 260, Wagstaff upgraded to its successor, the Extra 300S, in 1993. In 1996, she retired from competition, and in 2004, she was inducted into the National Aviation Hall of Fame.

ERIC LONG/NASM



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On January 24, 1848, James W. Marshall made the discovery that would change the course of American history forever. A gleam in the bottom of the ditch caught his eye and reaching in he scooped up a handful of dirt, examined it closely and concluded that what he had found appeared to be Gold. "I picked up one or two pieces and examined them attentively; I then collected four or five pieces and went up to Mr. Scott with the pieces in my hand and said, 'I have found it.' 'What is it?' Inquired Scott. 'Gold,' I answered".

The discovery sparked the California Gold Rush and became part of the 'American Dream'.

Inspired by the famous story Daniel Steiger created a watch in honor of the first Gold Flakes that Marshall discovered. Expertly crafted in solid stainless steel and lavish gold finished case complimented by elegant white gold foil dial; this beautifully crafted timepiece is the perfect must-have accessory for every gentleman. Placed at 6 and 12 o'clock positions are Swarovski crystals and a black croc grain leather strap completes the look. This watch will provide you with years of reliable service and is of course covered by our 5 year unlimited movement warranty. This exceptional man's timepiece is now available at the amazingly low price of $99, a quite remarkable saving of $660 off the original list price of $759. Presented in a magnificent case this is a truly unique opportunity to own high quality at an unbelievable price. A piece of American history on your wrist. Daniel Steiger – Quality that can't be beat!

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